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Society for Advancement of Rice Research

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- To honour outstanding achievers in rice research and development.
- To cooperate with other organizations having similar aims and objectives.
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Volume 14 : Issue No. 1 June 2021

Contents	Page No.

ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Effect of different genotypes and nitrogen levels on grain yield and quality of rice

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Abstract

Rice (*Oryza sativa* L.) is the only cereal crop cooked and consumed mainly as whole grains, and quality considerations are much more important than for any other food crop. Nevertheless, rice-grain quality depends not only on genetic background, but also on soil and climatic conditions, agronomic treatments during rice growth and development. Levels of nitrogen more easily affects rice growth and rice grain quality. A field experiment was conducted in split plot design comprised of thirty-two rice genotypes as main plots and four N levels (N_0 (control), N_1 (50 % RDN), N_2 (100 % RDN) and N_3 (150 % RDN) as sub-plots with three replications to assess the grain quality and cooking properties of rice. Highest grain yield were recorded at N_3 (180 kg ha^{-1}) by most of the rice genotypes, except AS 12051, ACK 14004, CB08702, CB 13539 and PM 12009 which have not responded for higher dose of nitrogen (180 kg ha^{-1}). Kernel length and kernel breadth before and after cooking was significantly influenced in the rice genotypes. EC725224 (G_{32}) exhibited highest mean length of 7.10 mm before cooking which elongated to 10.47 mm after cooking. All the rice genotypes showed a kernel breadth of less than 2.0 mm and considered as best. The highest mean amylose content of 26.11 % was obtained from the genotype TM09135 (G_{26}) followed by EC725224 (G_{32}) which recorded the mean amylose content of 24.91 % in rice.

Keywords: Rice genotypes, nitrogen, rice quality, kernel length, kernel breadth, amylose

Introduction

Rice (*Oryza sativa* L.) is the staple food for over half of the world population and it is ranked as the number one human food crop in world (Itani *et al*., 2002). More than 90% of world rice is grown and consumed in Asia (Tyagi *et al*., 2004), whereas 60% calories are consumed by 3 billion Asians. India is the second most populous nation, stands first in area, second in production of rice followed and preceded by China. Rice occupies a pivotal place in Indian food and livelihood security system. It provides about 75% of the average calories and 55 % of the protein in the average daily diet of the people (Anonymous, 2002). In India, rice occupies 44.6 m ha. Rice is the only cereal crop cooked and consumed mainly as whole grains, and quality considerations are much more important than for any other food crop (Hossain *et al*., 2009). Among the various cultural practices, fertilizer management is crucial factor, which influence the growth and yield of rice. A significant variation due to fertilizer levels was noticed in all the quality parameters. However, due to the pressure of grain supply, less attention is paid to improve rice-grain quality. With continuous economic development and rising standards of living, a preference for high grain quality gradually increases. Thus, improving rice quantity and quality is not only closely associated with the improvement of people's living conditions, but it is also a major response measure for ensuring world food security under extreme climate change and tremendous population growth. Many studies have reported on the genetic control of rice cultivar on the grain-shape, appearance-quality (Zhao *et al*., 2018), gel-consistency, gelatinization-temperature (Bao *et al*., 2002; He *et al*., 1999), and pasting-viscosity parameters (Bao, 2012). Bao *et al*. (2004) suggested that amylose content; final viscosity, breakdown, and setback were mainly influenced by genotypic variance.

Nevertheless, rice-grain quality depends not only on genetic background, but also on soil and climatic conditions, and agronomic treatments during rice growth and development. However, to date, information on how crop-management practices affect rice-grain quality is lacking. Giving more importance to genetic diversity in rice-breeding programs is crucial to improve rice quality, but this improvement could be seriously restricted in the absence of appropriate agricultural approaches. Thus, it is imperative to simultaneously consider genetic and management practices to achieve the target amelioration of rice-grain quality. Nitrogen (N) rate is key factor that affects rice-grain quality and growth of rice. Research in this field is of great significance not only for breeders, but also for producers, and has a direct effect on the production of high-quality grains. Our objective was to determine the effect of genotype and N application rates on rice-grain quality and to provide useful knowledge for achieving high-quality rice production.

Materials and Methods

A field experiment was conducted during *pishanam* season, 2017 at Agricultural Research Farm, Rice Research station, Ambasamudram, Tirunelveli, Tamil Nadu with split plot design comprising of thirty two rice genotypes *viz*. ASD16, ADT39, ADT43, ADT45, CO51, TPS5, MDU5, ANNA4, AS12051, AS12104, AD09206, AD10034, ACK14001, ACK14004, CB06803, CB08702, CB13539, CB14508, CB14533, TR09027, TR05031, TR13069, TR13083, TM13007, TM07335, TM09135, TM10085, TM12059, TM12061, TM12077, PM12009 and EC725224 as main plots and four N levels (N_0 (control), N_1 (50 % RDN), N_2 (100 % RDN) and N_3 (150 % RDN) as sub-plots with three replications to assess the grain quality and cooking properties of rice **(Table 1).** All the recommended package of practices were followed to raise a good crop. The nursery was raised separately for 32 different rice genotypes. The nursery for SRI was prepared as raised beds with dimension of 120 cm wide, 15 cm height including buffer channel half meter wide all round them to facilitate easy drainage. The water soaked seeds of rice genotypes were sown evenly in the line. Hand weeding also practiced to remove the weeds in the adjoining areas of rice haulm / plants at 45 and 60 DAT. The plots were irrigated with 2.5 cm depth of water and irrigated again on appearance of hairline cracks on the soil surface. This practice was continued till the flowering stage of the crop. The entire dose of P_2O_5 was applied as single super phosphate before planting. The one split dose of potassium was applied as muriate of potash (among four equal split doses) before planting and other 3 splits were applied at tillering (30 DAT), panicle initiation (60 DAT) and flowering stage (75 DAT). The N fertiliser (urea) was applied as per the treatment schedule. The urea was applied in four equal split doses during before planting (basal 25 %) and top dressing at tillering at 30 DAT (25 %), panicle initiation at 60 DAT (25 %) and flowering stage at 75 DAT (25 %). Data pertaining to different quality traits *viz*. kernel length, kernel breadth, kernel length after cooking, kernel breadth after cooking, size and shape of grain were recorded on five randomly selected grains of each replication. A simplified procedure was used for estimating the amylose content (Juliano 1971). Based on amylose content the rice was categorized as waxy, verylow, low, intermediate and high (**Table 2**; SES, 2002).

Results and Discussion

Grain yield

The results of the field experiment revealed that the grain yield of rice was significantly influenced by genotypes, nitrogen levels and their interaction. Among the genotypes, the highest grain yield of 6698 kg ha^{-1} was recorded by ASD16 which was on par with 6695 kg ha^{-1} recorded by TR13083 followed by TM12077 which produced the grain yield of 6162

Table 1: Details of the rice varieties/cultures

Factors	Genotype	Parentage	Variety / Cultivar	Duration (Short, medium, long)
Main plot (Rice genotypes)	ASD 16	ADT31xCO39	V	Short duration rice cultivars
	ADT 39	IR8 x IR20	V	
	ADT 43	IR50xwhite ponni	V	
	ADT 45	IR50 /ADT37	V	
	CO 51	ADT43xRR272-1745	V	
	TPS 5	ASD16 x ADT37	V	
	MDU 5	O.glaberrima x Pokkali	V	
	ANNA 4	Pantdhan10 x IET9911	V	
	AS 12051	BPT5204/ASD16	C	
	AS 12104	ADT(R) 45 / Raskadam	C	
	AD 09206	ADT43/ADT37	C	
	AD 10034	ADT(R) / Swarna	C	
	ACK 14001	ACK9009 / ASD16	C	
	ACK 14004	IR8 / ASD16	C	
	CB 06803	PMK(R) 3/Norungan	C	
	CB 08702	IR80013-B-141-4	C	
	CB 13539	ADT43/GEB24	C	
	CB 14508	ADT37/CB05501	C	
	CB 14533	Bhavani/CB05501	C	
	TR 0927	Mutant of TRY(R) 2	C	
	TR 05031	ADT39/CO45	C	
	TR 13069	ADT43 / FL478 /ADT43	C	
	TR 13083	ADT43 / FL478/ADT43	C	
	TM 13007	TKM13 x IET22565	C	
	TM 07335	ADT43 / CO47	C	
	TM 09135	IR82639-B-B-115-1	C	
	TM 10085	ADT43/CO47	C	
	TM 12059	ADT(R)45/Chandihar	C	
	TM 12061	Senthooram/Vandana	C	
	TM 12077	TKM (R)12 x IET21620	C	
	PM 12009	IR55419-4*2/way rarem	C	
	EC 725224	Philippine culture	C	

Table 2: Classification of rice genotypes based on size and shape of kernel

Length	Size	Amylose	Category
>7.50	Extra long	<0.00 to 2.00	Waxy
6.61to 7.50	Long	3.01 to 9.00	Very low
5.51 to 6.60	Medium	10.01 to 19.00	Low
5.5 or less	Short	20.00 to 25.00	Intermediate
		>25.00	High

kg ha^{-1} **(Table 3).** The lowest grain yield of 2433 kg ha^{-1} was observed in the genotype CB14533. With regards to nitrogen levels, increased mean grain yield of 4916, 5548 and 6072 kg ha^{-1} were recorded by the application of 50 % recommended dose of nitrogen (60 kg ha^{-1}), 100 % recommended dose of nitrogen (120 kg N ha^{-1}) and 150 % recommended dose of nitrogen (180 kg N ha^{-1}) than control (N_0) which yielded 4111 kg ha^{-1} of rice grains. The interaction effect between the nitrogen levels and rice genotypes significantly influenced the grain yield. The highest grain yield of 8150 kg ha^{-1} was observed under ASD16 with the application of 150 % recommended dose of nitrogen (G_1N_3) followed by TR13083 grown under same dose of nitrogen (180 kg N ha^{-1}) which produced 7333 kg ha^{-1} of grain yield. The lowest grain yield (1543 kg ha^{-1}) was obtained by the genotype CB14533 without nitrogen application (absolute control) followed by TR09027 which yielded 2878 kg ha^{-1} of grain. In all the genotypes, the grain yield increased from control due to the application of higher dose of nitrogen (180 kg N ha^{-1}) except AS12051, ACK14004, CB08702, CB13539 and PM12009. These genotypes recorded highest grain yield of 5864, 5536, 5287, 4754 and 3750 kg ha^{-1}at 100% recommended dose of nitrogen and the yield decreased at higher dose of 180 kg N ha^{-1} (150 % recommended dose of N).

A significant positive correlation observed between N uptake and dry matter production at tillering and panicle initiation **(Figure 1)** suggested maintaining N concentration on leaves during early vegetative stage is compulsory for maintaining higher biomass and yield. The uptake of nitrogen and utilization of absorbed N efficiently converted product of biomass production at tillering, panicle initiation and heading stages. Application of 150 % recommended dose of nitrogen (N_3) showed higher soil available nitrogen at tillering, panicle initiation, heading and harvest stages of rice (323, 295, 263 and 224 Kg ha^{-1}). The lowest soil available nitrogen (260, 231. 203 and 167 Kg ha^{-1}) was recorded under control at phenological stages of rice **(Figure 2).** The soil available N and the amount of N depletion are directly related and the amount of N addition and amount of N depletion is indirectly related with each other. The highest N depletion of 35.76 % was recorded under control and the lowest depletion of 30.65 % was recorded under N_{150}. Higher nitrogen content in soil after harvest reflected the higher dose of N application to the soil. This result is in agreement with findings of Majumdar (2005) and Roy *et al*., (2006). However, during the crop growth period the reduction in the soil available N could be attributed to the uptake by growing crop (Scandaliaris *et al*., 1987).

Kernel length and breadth

The quality parameters of kernel length and kernel breadth before and after cooking significantly influenced by the rice genotypes. EC725224 (G_{32}) exhibited highest mean length of 7.10 mm before cooking which elongated to 10.47 mm after cooking. Based on the standard system of evaluation of rice kernels, the rice genotypes AS16, ADT39, ADT43, TPS5, AS12051, AS12104, AD09206, AD10034, ACK14001, ACK14004, CB06803, CB13539, Cb14508, TR05031, TR13069, TM07335, TM10085, TM12059, TM12061 and TM12077 were categorized as shorter kernel varieties whereas the genotypes such as ADT45, CO51, MDU5, ANNA4, CB08702, CB14533, TR09027, TR13007, TM12009 and TM09135 as medium kernel varieties and the genotype EC725224 as long kernel variety **(Table 3 and 4)**. The varieties with kernel breadth of less than 2.0 mm are considered as best category rice genotypes (Singh *et al*., 2012). In this experiment, all the rice genotypes showed a kernel breadth less than 2.0 mm **(Table 5,6 and 7).** The quality parameters of kernel length and kernel breadth before and after cooking increased with increasing level of nitrogen which may be due to the fact that nitrogen is the principal constituent of protein. This is in corroboration with the findings of Subudhi *et al*., (2012).

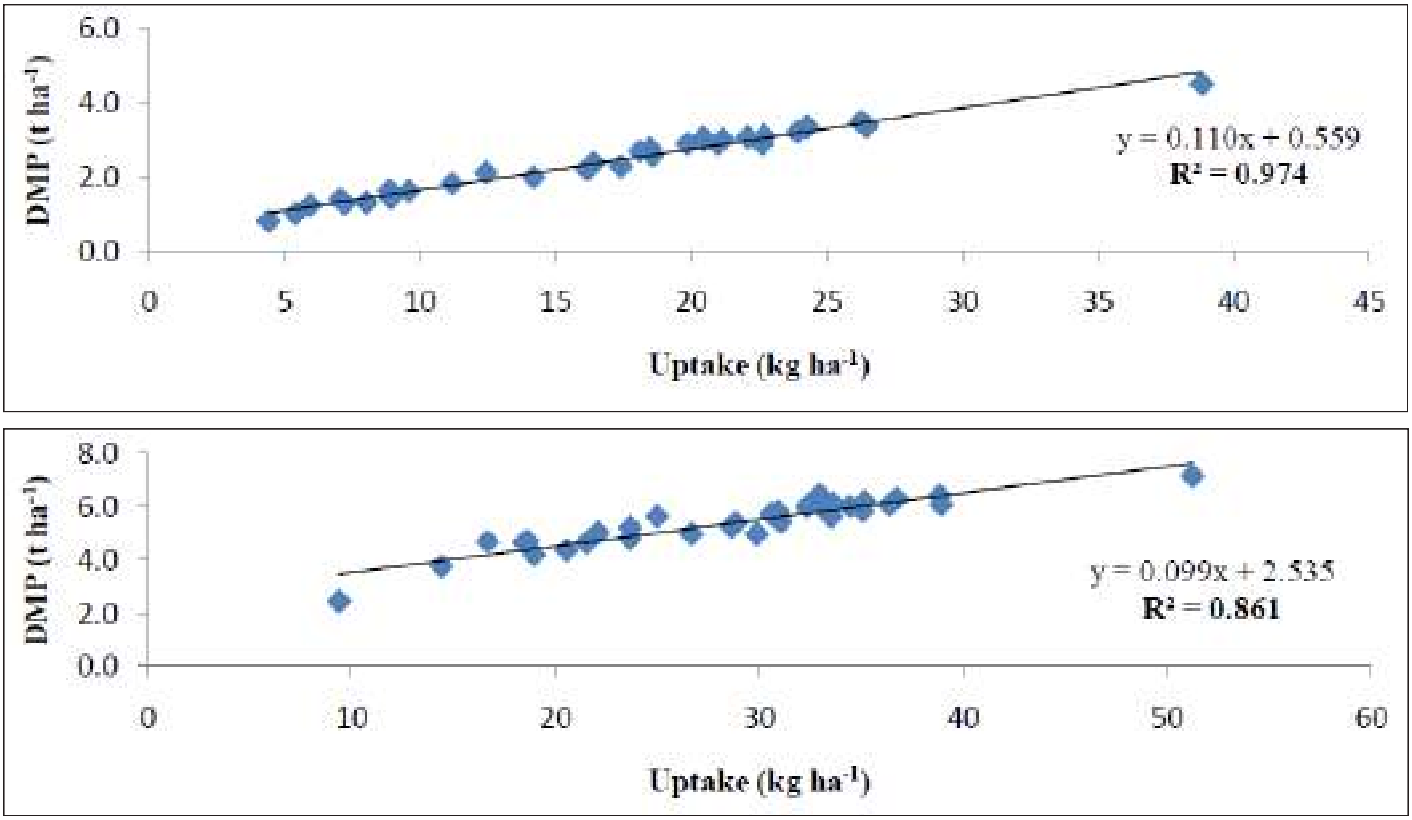

Figure 1: Regression between nitrogen uptake and dry matter production as influenced by rice genotypes at tillering and panicle initiation

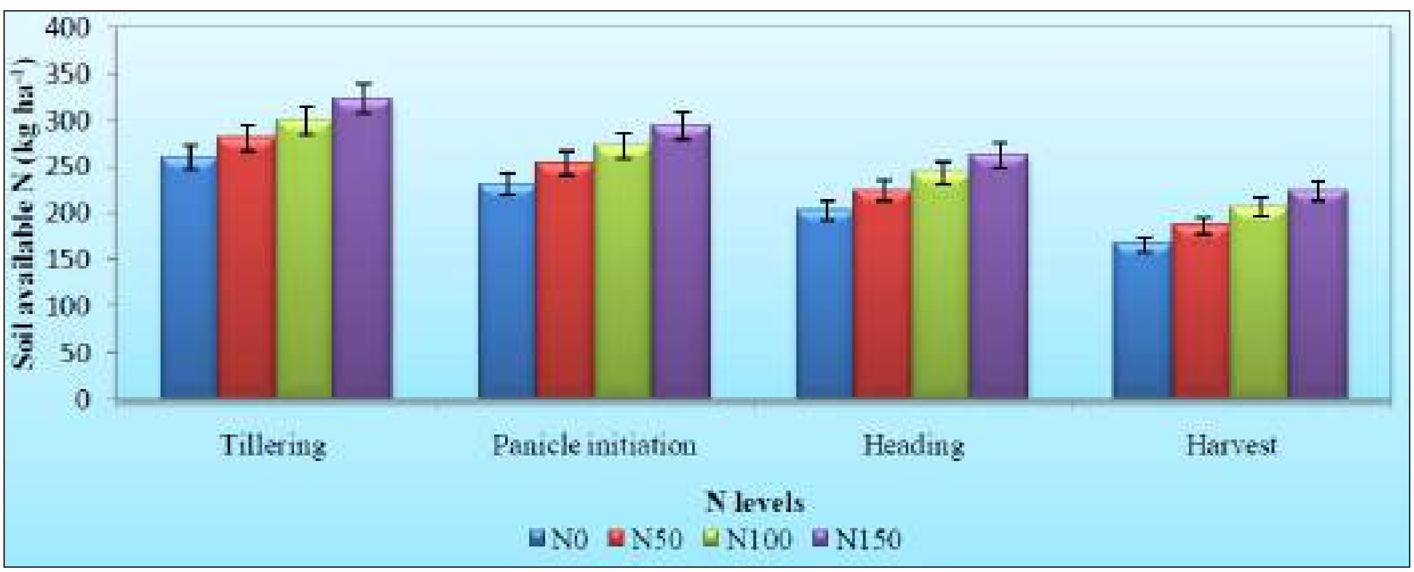

Figure 2: Soil available N as influenced by the levels of N application at different stages of rice

Table 3: **Grain yield (kg ha^{-1}) of rice influenced by genotypes and levels of nitrogen application**

S.No	Genotypes/ Varieties	N_0	N_1	N_2	N_3	Mean
1	ASD 16	5284	6175	7183	8150	6698
2	ADT 39	3682	4921	5778	6814	5299
3	ADT 43	4259	4691	5500	6723	5293
4	ADT 45	4606	5339	6299	7256	5875
5	CO 51	4587	4940	5576	6371	5368
6	TPS 5	3643	4660	5550	5924	4944
7	MDU 5	5549	5660	6188	6659	6014
8	ANNA 4	5289	5355	5512	5577	5433
9	AS 12051	3889	4410	4754	4681	4433
10	AS 12104	4556	5493	6226	6428	5676
11	AD 09206	3254	4374	4969	5372	4492
12	AD 10034	4968	5317	5390	5497	5293
13	ACK 14001	4837	5844	6678	6929	6072
14	ACK 14004	4510	5549	5864	5771	5423
15	CB 06803	3536	4775	5542	6012	4966
16	CB 08702	4335	4811	5287	5078	4878
17	CB 13539	3029	3401	3750	3429	3402
18	CB 14508	4350	5156	6144	7051	5675
19	CB 14533	1543	2030	2526	4420	2629
20	TR 0927	2878	3291	4294	5107	3892
21	TR 05-31	4632	5895	6275	6717	5880
22	TR 13069	3811	4204	4795	5873	4671
23	TR 13083	5778	6479	7188	7333	6695
24	TM 1307	5056	5762	6220	6627	5916
25	TM 07335	4947	5495	6209	6862	5878
26	TM 09135	3660	4594	4890	5502	4661
27	TM 10085	3673	5015	6051	7157	5474
28	TM 12059	3868	4587	5085	5512	4763
29	TM 12061	2911	3322	4542	5438	4053
30	TM 12077	4304	6020	7119	7206	6162
31	PM 12009	3372	5222	5536	5418	4887
32	EC 725224	2956	4517	4611	5419	4376
	Mean	**4111**	**4916**	**5548**	**6072**	**5162**
		G	**N**	**G x N**	**N x G**	
	SE d	30.34	11.16	62.53	63.13	-
	CD	61.84	22.15	124.92	125.31	-

Table 4. Kernel length before cooking (mm) of rice genotypes as influenced by nitrogen application

S.No	Treatments	N_0	N_{50}	N_{100}	N_{150}	Mean
1	ASD 16	5.30	5.33	5.34	5.36	5.33^{m}
2	ADT 39	5.18	5.24	5.27	5.43	5.28^{no}
3	ADT 43	5.33	5.35	5.42	5.49	5.40^{l}
4	ADT 45	6.07	6.13	6.15	6.18	6.13^{f}
5	CO 51	5.46	5.55	5.64	5.72	5.59^{i}
6	TPS 5	4.97	5.33	5.48	5.48	5.31^{n}
7	MDU 5	6.10	6.11	6.13	6.15	6.12^{f}
8	ANNA 4	6.16	6.21	6.41	6.50	6.32^{c}
9	AS 12051	5.26	5.25	5.71	5.76	5.49^{k}
10	AS 12104	5.00	5.06	5.11	5.15	5.08^{u}
11	AD 09206	5.04	5.15	5.29	5.41	5.22^{pq}
12	AD 10034	5.09	5.21	5.24	5.26	5.20^{qrs}
13	ACK 14001	5.22	5.25	5.25	5.28	5.25^{op}
14	ACK 14004	5.05	5.12	5.37	5.37	5.22^{pq}
15	CB 06803	5.00	5.43	5.44	5.48	5.33^{m}
16	CB 08702	5.87	6.33	6.57	6.57	6.33^{c}
17	CB 13539	5.12	5.17	5.21	5.24	5.18^{rst}
18	CB 14508	5.06	5.13	5.19	5.24	5.15^{t}
19	CB 14533	5.66	5.69	5.87	5.89	5.77^{h}
20	TR09027	6.15	6.22	6.30	6.42	6.27^{d}
21	TR05031	5.04	5.14	5.23	5.33	5.18^{rst}
22	TR 13069	5.33	5.36	5.48	5.80	5.49^{k}
23	TR 13083	5.44	5.49	5.63	5.67	5.55^{j}
24	TR13007	5.97	6.00	6.05	6.05	6.02^{g}
25	TM 07335	4.75	4.83	4.97	4.98	4.88^{v}
26	TM 09135	6.35	6.37	6.56	6.72	6.50^{b}
27	TM 10085	4.76	4.77	4.99	5.05	4.89^{v}
28	TM 12059	4.92	5.06	5.22	5.47	5.16^{st}
29	TM 12061	5.22	5.24	5.27	5.33	5.26^{o}
30	TM 12077	5.15	5.21	5.24	5.25	5.21^{qr}
31	PM 12009	6.07	6.21	6.23	6.34	6.21^{e}
32	EC 725224	6.95	7.17	7.14	7.17	7.10^{a}
	Mean	**5.30^{d}**	**5.33^{c}**	**5.34^{b}**	**5.36^{a}**	**5.33**
		G	**N**	**G × N**	**N× G**	
	SE d	0.01	0.006	0.03	0.03	
	CD (P =0.05)	0.03	0.012	0.06	0.07	

Table 5. Kernel length after cooking (mm) of rice genotypes as influenced by nitrogen application

S.No	Treatments	N_0	N_{50}	N_{100}	N_{150}	Mean
1	ASD 16	8.74	8.84	8.84	8.75	8.79^{e}
2	ADT 39	8.63	8.64	8.67	8.66	8.65^{h}
3	ADT 43	8.55	8.56	8.66	8.67	8.61^{i}
4	ADT 45	8.11	8.14	8.18	8.18	8.15^{m}
5	CO 51	8.36	8.38	8.41	8.45	8.40^{k}
6	TPS 5	7.07	7.72	7.78	7.83	7.60^{u}
7	MDU 5	8.19	8.23	8.24	8.27	8.23^{l}
8	ANNA 4	8.52	8.57	8.61	8.62	8.58^{i}
9	AS 12051	7.73	7.75	8.08	8.14	7.92^{o}
10	AS 12104	7.04	7.06	7.12	7.18	7.10^{x}
11	AD 09206	7.64	7.68	7.72	7.73	7.69^{s}
12	AD 10034	7.61	7.75	7.74	7.79	7.72^{rs}
13	ACK 14001	7.82	7.85	7.88	7.90	7.86^{p}
14	ACK 14004	7.67	7.75	7.80	7.81	7.75^{q}
15	CB 06803	7.56	7.74	7.78	7.81	7.72^{rs}
16	CB 08702	8.04	8.62	8.75	8.76	8.54^{j}
17	CB 13539	7.52	7.58	7.67	7.68	7.61^{u}
18	CB 14508	7.02	7.09	7.18	7.24	7.13^{w}
19	CB 14533	6.83	6.88	7.01	7.11	6.95^{y}
20	TR09027	8.82	8.92	8.98	8.98	8.92^{d}
21	TR05031	7.57	7.63	7.69	7.75	7.66^{t}
22	TR 13069	8.57	8.62	8.77	8.78	8.68^{g}
23	TR 13083	7.87	7.92	8.02	8.08	7.97^{n}
24	TR13007	8.71	8.78	8.78	8.78	8.76^{f}
25	TM 07335	5.76	5.88	5.94	5.96	5.88^{z}
26	TM 09135	9.45	9.46	9.50	9.62	9.50^{c}
27	TM 10085	7.22	7.26	7.47	7.68	7.40^{v}
28	TM 12059	7.76	8.29	8.35	8.41	8.20^{l}
29	TM 12061	7.70	7.72	7.74	7.78	7.73^{q}
30	TM 12077	7.53	7.59	7.64	7.65	7.60^{u}
31	PM 12009	9.52	10.20	10.23	10.28	10.05^{b}
32	EC 725224	9.85	10.65	10.67	10.73	10.47^{a}
	Mean	**7.97^{d}**	**8.11^{c}**	**8.18^{b}**	**8.22^{a}**	**8.12**
		G	**N**	**G × N**	**N× G**	
	SE d	0.01	0.003	0.02	0.02	
	CD (P =0.05)	0.03	0.006	0.04	0.04	

Table 6. Kernel breadth before cooking (mm) of rice genotypes as influenced by nitrogen application

S.No	Treatments	N_0	N_{50}	N_{100}	N_{150}	Mean
1	ASD 16	1.42	1.46	1.45	1.45	1.45^{d}
2	ADT 39	1.12	1.17	1.19	1.19	1.17^{pq}
3	ADT 43	1.09	1.15	1.21	1.25	1.17^{p}
4	ADT 45	1.24	1.26	1.34	1.35	1.29^{i}
5	CO 51	1.10	1.13	1.19	1.21	1.16^{q}
6	TPS 5	1.23	1.41	1.43	1.52	1.40^{e}
7	MDU 5	1.46	1.46	1.49	1.51	1.48^{c}
8	ANNA 4	1.33	1.36	1.35	1.36	1.35^{h}
9	AS 12051	1.23	1.25	1.26	1.31	1.26^{j}
10	AS 12104	1.14	1.17	1.19	1.20	1.17^{pq}
11	AD 09206	1.19	1.18	1.17	1.18	1.18^{p}
12	AD 10034	1.01	1.09	1.09	1.09	1.07^{r}
13	ACK 14001	1.47	1.52	1.60	1.62	1.52^{a}
14	ACK 14004	1.29	1.28	1.27	1.34	1.29^{i}
15	CB 06803	1.44	1.47	1.55	1.56	1.50^{b}
16	CB 08702	1.36	1.35	1.39	1.43	1.38^{f}
17	CB 13539	1.16	1.19	1.22	1.28	1.21^{no}
18	CB 14508	1.47	1.47	1.51	1.52	1.49^{bc}
19	CB 14533	1.21	1.27	1.27	1.28	1.26^{j}
20	TR09027	1.16	1.18	1.26	1.32	1.23^{lm}
21	TR05031	1.14	1.15	1.18	1.22	1.17^{pq}
22	TR 13069	1.25	1.27	1.30	1.35	1.29^{i}
23	TR 13083	1.25	1.25	1.27	1.31	1.27^{j}
24	TR13007	1.24	1.25	1.22	1.25	1.24^{kl}
25	TM 07335	1.14	1.17	1.19	1.19	1.17^{pq}
26	TM 09135	1.31	1.34	1.42	1.43	1.37^{fg}
27	TM 10085	1.19	1.26	1.27	1.30	1.25^{jk}
28	TM 12059	1.20	1.21	1.22	1.26	1.22^{mn}
29	TM 12061	1.17	1.19	1.22	1.24	1.20^{o}
30	TM 12077	1.09	1.10	1.11	1.41	1.18^{p}
31	PM 12009	1.33	1.41	1.42	1.44	1.40^{e}
32	EC 725224	1.32	1.34	1.37	1.43	1.36^{gh}
	Mean	**1.24^{d}**	**1.27^{c}**	**1.30^{b}**	**1.33^{a}**	**1.28**
		G	**N**	**G × N**	**N× G**	
	SE d	0.007	0.002	0.01	0.01	
	CD (P =0.05)	0.014	0.005	0.03	0.03	

Table 7. Kernel breadth after cooking of rice genotypes as influenced by nitrogen application

S.No	Treatments	N_0	N_{50}	N_{100}	N_{150}	Mean
1	ASD 16	1.52	1.96	2.40	2.43	2.08^{d}
2	ADT 39	1.22	1.67	2.14	2.17	1.80^{pq}
3	ADT 43	1.19	1.65	2.16	2.23	1.81^{p}
4	ADT 45	1.34	1.76	2.29	2.33	1.93^{i}
5	CO 51	1.20	1.63	2.14	2.19	1.79^{q}
6	TPS 5	1.33	1.91	2.38	2.50	2.03^{e}
7	MDU 5	1.56	1.96	2.44	2.49	2.11^{c}
8	ANNA 4	1.43	1.86	2.30	2.34	1.98^{h}
9	AS 12051	1.33	1.75	2.21	2.29	1.89^{j}
10	AS 12104	1.24	1.67	2.14	2.18	1.80^{pq}
11	AD 09206	1.29	1.68	2.12	2.16	1.81^{p}
12	AD 10034	1.11	1.59	2.04	2.07	1.70^{r}
13	ACK 14001	1.57	2.02	2.48	2.55	2.15^{a}
14	ACK 14004	1.39	1.78	2.22	2.32	1.93^{i}
15	CB 06803	1.54	1.97	2.50	2.54	2.13^{b}
16	CB 08702	1.46	1.85	2.34	2.41	2.01^{f}
17	CB 13539	1.26	1.69	2.17	2.26	1.84^{no}
18	CB 14508	1.57	1.97	2.46	2.50	2.12^{bc}
19	CB 14533	1.31	1.77	2.22	2.26	1.89^{j}
20	TR09027	1.26	1.68	2.21	2.30	1.86^{lm}
21	TR05031	1.24	1.65	2.13	2.20	1.80^{q}
22	TR 13069	1.35	1.77	2.25	2.33	1.92^{i}
23	TR 13083	1.35	1.75	2.22	2.29	1.90^{j}
24	TR13007	1.34	1.75	2.17	2.23	1.87^{l}
25	TM 07335	1.24	1.67	2.14	2.17	1.80^{pq}
26	TM 09135	1.41	1.84	2.37	2.41	2.00^{fg}
27	TM 10085	1.29	1.76	2.22	2.28	1.89^{jk}
28	TM 12059	1.30	1.71	2.17	2.24	1.85^{mn}
29	TM 12061	1.27	1.69	2.17	2.22	1.83^{o}
30	TM 12077	1.19	1.60	2.06	2.39	1.81^{p}
31	PM 12009	1.43	1.91	2.37	2.42	2.03^{e}
32	EC 725224	1.42	1.84	2.32	2.41	1.99^{gh}
	Mean	**1.34^{d}**	**1.77^{c}**	**2.25^{b}**	**2.31^{a}**	**1.92**
		G	**N**	**G × N**	**N× G**	
	SE d	0.007	0.002	0.01	0.01	
	CD (P =0.05)	0.014	0.005	0.03	0.03	

Amylose content

Amylose content is the major factor for judging eating quality (Juliano and Hicks, 1996). It determines the hardness or stickiness of cooked rice, cohesiveness, tenderness, colour of cooked rice etc. The higher amylose content (>25.0%) gives non sticky soft or hard cooked rice. Rice varieties having 20-25% amylose content gives soft and flaky cooked rice. It was also used as an indicator of volume expansion on water absorption during cooking (Denyer *et al*., 2001). Intermediate amylose content (20-25%) is usually preferred by Indians. In this study, all the tested genotypes had intermediate amylose content except EC725224. Among the genotypes, the highest mean amylose content of 26.11 % was obtained from the genotype TM09135 (G_{26}) followed by EC725224 (G_{32}) which recorded the mean amylose content of 24.91 % in rice. The lowest mean amylose content of 19.55 % was recorded in the genotype TR13069 (G_{22}) **(Figure 3).**

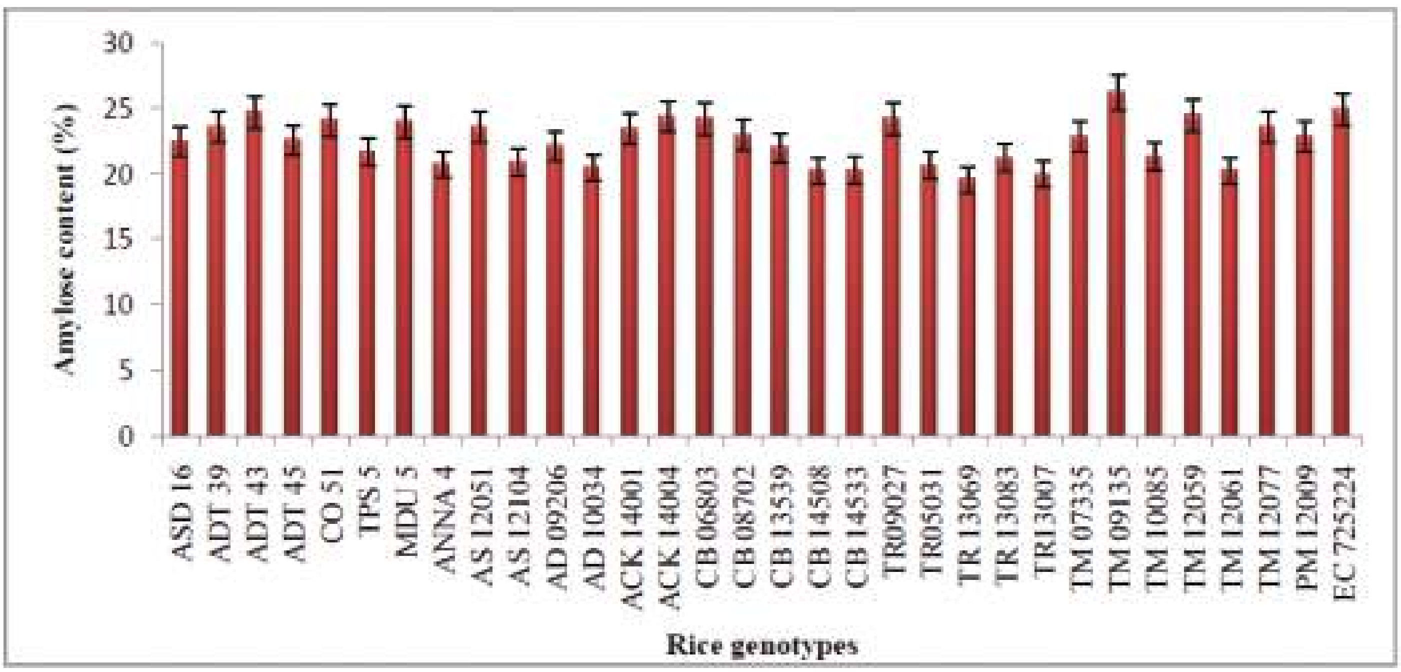

Figure 3: Amylose content (%) as influenced by rice genotypes

Amylose content decreased with increased level of nitrogen application in the study **(Figure 4).** It might be due to increase in the activation of starch branching enzymes and as a result amylopectin percentage increased and amylose content decreased (Zadeh and Hashemi, 2014). With respect to nitrogen levels, the highest mean amylose content of 23.63 was observed under control followed by the application of 50 % recommended dose of nitrogen (23.11 %). The lowest amylose content of 21.32 % was observed by the application of 150 % recommended dose of nitrogen. Among the interaction, the highest amylose content of 27.75 % present in the genotype TM09135 under no nitrogen application followed by 26.95 % was recorded by the same genotype under 50 % recommended dose of nitrogen. The minimum quantity of 16.56 % was observed by the genotype ANNA4 with 150 % recommended dose of nitrogen (G_8N_3). This result was in conformity with the reported work of Dong *et al*., (2007).

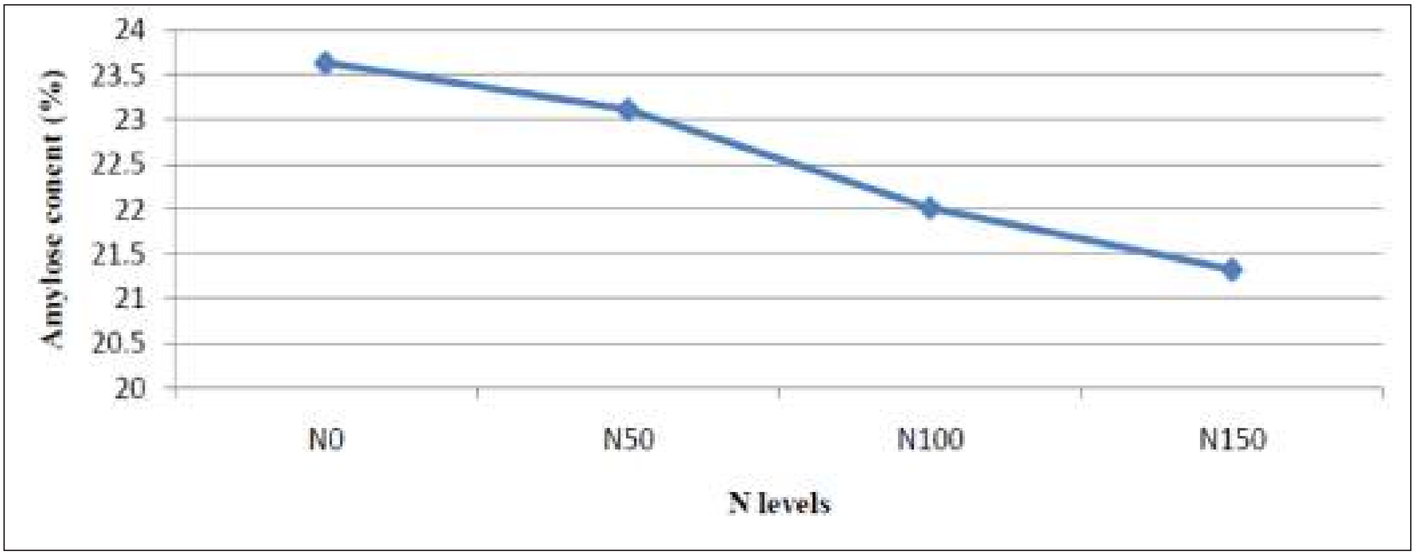

Figure 4: Amylose content (%) as influenced by levels of nitrogen application

Conclusion

This study conducted on 32 rice genotypes collected from Tamilnadu, revealed the variability of genotypes and nitrogen application on their physical and chemical characteristics. Genotypes were highly significant in physical and chemical characteristics such as shape and amylose content of the rice. High variation among the rice genotypes was obtained in the characteristics like grain yield, kernel length, kernel breadth and amylose content. Some of the genotypes showed noble physico-chemical characteristics that can fetch premium prices especially the exotic variety EC725224 showed higher length and breadth before and after cooking and it is mainly used for biryani making. Based on the amylose content we can conclude the storage determination for rice taste. Amylose and amylopectin determines the cooking quality of rice. Indians mostly prefer non sticky rice varieties which have higher amylose content of 25% - 30%, when it will be stored the amylose content gets reduced and the rice will become soft. So, most of the consumers prefer old rice. The information obtained through this study could be used in rice breeding programmes and molecular research for further improvement of rice and it may help food processors to produce a good quality of cooked rice by controlling the amylose content.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Biochar - A climate smart practice for milling traits and aroma of fragrant rice under drought stress with different time of harvest

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Abstract

A pot experiment was conducted at research area under plastic net house of Sher-e-Bangla Agricultural University, Dhaka-1207 during 2019-20. BRRI dhan50 was used as planting material. The experiment was laid out in 2x2x3 factorial design with five replications and comprised of three factors *viz*., Factor-1 (Biochar-2 levels): B_1 = (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}; Factor-2 (Drought stress-2 levels): D_1= At reproductive stage, D_2= At grain filling stage and Factor-3 (Time of harvest-3 levels): H_1= 3 weeks after flowering, H_2= 4 weeks after flowering and H_3= 5 weeks after flowering. Application of biochar @ 5tha^{-1} along with drought stress imposed at grain filling stage and crop harvested 5 weeks after flowering showed the best result for brown rice yield, head rice recovery, amylose content, protein content, grain aroma and taste of BRRI dhan50. Application of biochar also increased soil organic carbon content. It can be concluded from the present study that, biochar application can help in reducing atmospheric carbon emitted from puddled rice soil in normal field condition under climate smart technology.

Keywords: Biochar, milling traits, 2-AP, drought stress, time of harvest, fragrant rice.

Introduction

Due to special appeal for aroma and acceptability, fine rice is mainly used by the people in the preparation of special traditional dishes and sold at a higher price in the market. Each year around 50 thousand tons of aromatic rice has been imported by Bangladesh from neighboring countries (Bayes, 2003). Islam *et al*., (1996) observed that the yield of aromatic rice is much lower than those of other rice growing countries due to lack of improved variety and judicious agronomic management. Still Bangladesh has a bright prospect for producing export quality aromatic rice and thus earning more foreign exchange. The long slender grains, intermediate amylose content, intermediate gelatinization temperature, high elongation ratio, strong aroma, softness, whiteness, stickiness, glossiness and translucency are the main basic standards for exporting the fine rice to the foreign countries (Deveriya, 2007). So, these characteristics should be determined and improved in local aromatic rice. The yield and aroma of fragrant rice can be increased through selection of appropriate variety and management practices *viz*., fertilizers, utilization of volatile compounds, cultivation practices and harvesting time. The production of aromatic volatile compounds are genetically controlled but the concentrations are also affected by other factors such as environment, climate, location and nutrient elements (Yoshihashi *et al*., 2004). Climate change through the increase in atmospheric CO_2 threatens the present and future agriculture in Bangladesh due to more carbon emission. Under such conditions, application of biochar to agricultural soils is considered as a promising strategy. It is attracting attention as a means for sequestering carbon and as a potentially valuable input for agriculture to rehabilitate degraded land, aid sustainable production and improve crop quality. Graber *et al*., (2010) mentioned that treating some crop plants by biochar positively enhanced yield and quality. Drought stress results in the increase of various osmotic compounds. One of the osmotic compounds from nitrogen group that significantly increase in a drought-stressed plant is proline amino acid (Arsa *et al*., 2017). In non-aromatic rice, proline will change into glutamate acid while in aromatic rice, biosynthesis process will produce 2-Acetil-1-Pyrrolin or 2AP (Fitzgerald *et al*., 2010). Hence, proline has the capacity to increase the amount of aroma in fragrant rice under optimum drought stress. Although grain yield and quality traits of aromatic rice are highly influenced by temperature particularly at the time of flowering, grain filling, at maturity and depend on the right time of harvest (Rohilla *et al*., 2000) . However, the farmers usually harvest aromatic rice at or beyond the full maturity stage and keep it in the field to dry for a long time in Bangladesh. Therefore, the present study was felt essential to evaluate the performance of aromatic rice cultivars through appropriate harvesting time to get maximum grain quality and aroma. The experiment was aimed to show the response of biochar on soil health and aroma of fragrant rice, to evaluate the proper state of drought stress on better milling traits and aroma of fragrant rice and also select the optimum time of harvest on aroma of fragrant rice.

Materials and Methods

1) *Experimental location with edaphic status*

A pot experiment was conducted under plastic net house of Sher-e-Bangla Agricultural University, Dhaka-1207. The experimental area was located in 23°7'N latitude and 93°E' longitude at an altitude of 8.6 meter above the sea level (Anon, 2004) and belonged to agro-ecological zone of "Madhupur Tract", AEZ-28. The experimental site was characterized by winter with a significant monsoon climate with sub-tropical cropping zone during the months of October 25, 2019 to April 10, 2020 (Rabi season). The soil above the sub-surface soil termed "Surface soil" was silty clay with slight sandy loam in texture, olive-slight grayish white with common fine to medium distinct dark whitish, brownish-light brown mottles was used as top soil in the study. The experimental area was medium flat and medium high topography with available easy irrigation and drainage system for setting the pots.

2) *Crop characters*

BRRI dhan50 variety was used for the study. The seeds were collected from Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur. The varietal characteristics include plant height of 82 cm, very low lodging, long, slender, white and aromatic kernel and grain protein per cent of 8.2. It has pleasant aroma similar to that of Basmati rice.

3) *Experimental treatments and design*

The experiment comprised of three factors *viz*., Factor-1 (Biochar-2 levels): B_1 = (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}; Factor-2 (Drought stress-2 levels): D_1= At reproductive stage, D_2= At grain filling stage and Factor-3 (Time of harvest-3 levels): H_1= 3 weeks after flowering (WAF), H_2= 4 WAF and H_3= 5 WAF. A 2×2×3 factorial design was followed under present study. Each treatment was represented by a single pot and replicated 5 times. Hence, a total of 60 pots were used in the study.

4) ***Seed sowing, pot preparation and seedling transplanting***

Healthy seeds were selected by specific gravity method and then immersed in water bucket for 24 hours and kept tightly in gunny bags. After 48 hours the seeds started sprouting and were sown in the pot after 72 hours. The seedbed was prepared with 1 m width adding nutrients as per the requirements of soil. Sprouted seeds were sown in the seed bed @ 70 g m^{-2} on 25 October, 2019. A 12 cm diameter plastic pot was used in the present study and 10 Kg field soil was poured per pot. Thirty-five (35) days old seedlings were transplanted in the puddled pot with intensive care. Initially two to three seedlings were planted per pot and then after recovery stage a single healthy seedling was maintained per pot.

5) ***Application of biochar, fertilizer and drought stress***

Biochar was collected from biochar production farm, Savar, Dhaka. After collection, the larger sized biochar was pressed by hammer to convert into fine sized particles for application in pot . The biochar was applied as per treatment during the final pot preparation. Chemical fertilizers such as urea, TSP, MOP, Gypsum, and Zinc sulphate was applied @ 260-90-150-110-11 kg ha^{-1}, respectively (BRRI, 2016) by using hectare slice as weight basis taking the weight of soil 2.0×10^{6} Kg/ha. All the fertilizer was applied as basal dose except urea which was applied as top dressing in 3 equal installments, at 15 DAT, tillering and before panicle initiation stage. No water was applied to induce two levels of drought stress at reproductive stage and at grain filling stage, while during the remaining period, water application was done as per crop the requirement.

6) ***Phytosanitary approaches***

Timely uprooting and removal of weeds from the pots was done wherever required at first tiller initiation stage, heading stage, anthesis stage and grain filling stage to maintain healthy and clean micro climate in the pots. Need based pesticide application was done to keep the potted plants free from insect and pathogen attack.

7) ***Crop harvest***

The crop was harvested at full maturity when about 80% of the seeds became golden yellow on April 10, 2020. The harvested crop was bundled separately, properly tagged before transfer to threshing floor. The grains of each pot were dried, cleaned and weighed after adjusting to 12% moisture content.

8) ***Data collection*:** The following parameters were recorded.

i) ***Brown rice (BR) yield***

Using a standard dehusker, 100 grams of rough rice seeds were dehulled and the average whole-grain BR yield was determined (Cruz and Khush, 2000; Chakraborty *et al*., 2016).

ii) ***Head rice recovery (HRR)***

Hundred grams' weight of de-hulled rice grains that had no visible breakage and ¾ size grains were used to determine the head rice recovery. Using the standard formula, the percentage of HRR and broken rice were calculated (Chakraborty *et al*., 2016).

iii) ***Chalkiness of endosperm***

By observing under stereo-zoom microscope the degree of chalkiness was determined using milled rice. Based on the observation the chalkiness of the endosperm was classified into white belly (WB), white center (WC) and white back (WB) (Cruz and Khush, 2000; Chakraborty *et al*., 2016).

iv) ***Chalk index determination***

Ten de-husked rice grains were placed on light box and the grain with more than 50% of chalkiness was visually identified, weighed and percentage of chalkiness was calculated (Cruz and Khush, 2000; Chakraborty *et al*., 2016).

v) Amylose percentage

The amylose content of the rice samples was worked out using method of Juliano (1971). Hundred mg of the powdered rice sample was taken in a volumetric flask and added with 1 ml of 95% ethanol and 9 ml of 1M NaOH followed by heating in boiling water bath to gelatinize starch. Five ml of the starch extract was taken in 100 ml volumetric flask and added with 1 ml of 1N acetic acid and 2 ml iodide solution making up the volume to 100 ml. The solution was shaken and allowed to stand for 20 min. Then the absorbance was measured at 620 nm using Agilent Technologies Cary 60 UV-VIS spectrophotometer and amylose content was determined with reference to the standard curve of potato amylose and expressed in per cent basis.

vi) Protein content

The protein content of rice grains was determined by the Micro-Kjeldahl method using automated nitrogen determination system (AOAC, 1990).

vii) Aroma and taste

Five grams of rice was added with 15 mL of water soaked for 10 min followed by cooking for 15 min and transferred into a Petri dish before placing in refrigerator for 20 min. The cooked rice then evaluated for aroma by a random panel and categorized as: strongly scented (SS); mild scented (MS) and non-scented (NS) (Sood and Siddiq, 1978 and Chakraborty *et al*., 2016). The panel consisted of twenty (20) randomly selected undergraduate and post-graduate students divided into four replications with, 5 students in each replication and the responses from each replication were summarized into SS, MS, and NS as described above. Same procedure was followed to assess by tasting the cooked rice and classifying it as sweet, salty or sour.

viii) Soil pH and soil carbon (%)

Data on soil pH and carbon (%) was collected on pre-transplanting and post-harvest basis from pots using a digital pH meter and standard methods of carbon determination, respectively.

9) Statistical package used

The data obtained for different parameters were statistically analyzed by computer-based software Statistix-10 using ANOVA technique and mean separation was done by LSD at 5% level of significance.

Results and discussion

i) Brown rice yield

A significant response was found in case of brown rice yield against biochar levels **(Table 1)**. B2 yielded higher (72.858 %) than B_1 (62.997 %). Drought stress also significantly influenced the brown rice yield **(Table 2)** and higher brown rice yield was recorded in D_2 (69.937 %) compared to D_1 (65.918 %). The data on influence of harvesting time **(Table 3)** revealed that highest brown rice yield was found from H_3 (69.589 %) on par with H_2, while the lowest yield was in H_1 (63.477 %). There was a significant interaction effect of the combination application of biochar, drought and harvesting time on the brown rice yield **(Table 4)**. The highest brown rice yield was found from $B_2D_2H_3$ (80.247 %) statistically similar to $B_2D_2H_2$ and $B_2D_1H_2$ while the lowest was in $B_1D_1H_1$ (56.557 %).

ii) Head rice recovery

In case of head rice recovery, there was a significant response due to biochar levels **(Table 1).** The HRR higher in B_2 (64.428 %) compared to B_1 (56.425 %). Drought stress also significantly influenced the head rice recovery **(Table 2)**. D_2 (62.238 %) showed higher HRR than D_1 (58.615 %). Harvesting time showed a significant effect on HRR **(Table 3)**. The highest head rice recovery was found from H_3 (62.149 %) which was statistically similar to H_2, while there was lowest in H_1 (56.422 %). Interaction effects were significant **(Table 4)** and $B_2D_2H_3$ (71.367 %) showed highest HRR on par with $B_2D_2H_2$ and $B_2D_1H_2$. HRR was least in $B_1D_1H_1$ (50.557 %).

iii) Chalk index determination

In case of chalk index, there was a significant response due to biochar levels **(Table 1)** and B_1 (40.920 %) showed higher index than B_2 (33.395 %). Effect of drought stress on chalk index was also evident as D_1 (38.972 %) and D_2 (35.343 %) showed significant differences **(Table 2)**. Similar trend was observed in the effect of harvesting time **(Table 3)**. The highest chalk index was found in H_1 (38.497 %) followed by H_2 and the lowest was in H_3 (36.072 %). Interaction effects showed highest chalk index in $B_1D_1H_1$ (43.067 %) statistically similar to $B_1D_1H_2$ while the lowest was in $B_2D_2H_2$ (30.207 %) on par with $B_2D_2H_3$ and $B_2D_2H_1$ **(Table 4)**.

Table-1. Effect of biochar levels on the milling traits of BRRI dhan50

Biochar levels	Brown rice yield (%)	Head rice recovery (%)	Chalk index determination (%)
B_1	62.997 b	56.425 b	40.920 a
B_2	72.858 a	64.428 a	33.395 b
CV (%)	4.79	5.79	3.63
LSD $_{(0.05)}$	2.250	2.419	0.931
F-test	**	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. **, indicate 1% level of probability; B_1= (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}

Table-2. Effect of drought stress on the milling traits of BRRI dhan50

Drought stress	Brown rice yield (%)	Head rice recovery (%)	Chalk index determination (%)
D_1	65.918 b	58.615 b	38.972 a
D_2	69.937 a	62.238 a	35.343 b
CV (%)	4.79	5.79	3.63
LSD $_{(0.05)}$	2.250	2.419	0.931
F-test	**	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. **, indicate 1% level of probability; D_1= At reproductive stage, D_2= At grain filling stage

Table-3. Effect of harvesting time on the milling traits of BRRI dhan50

Time of harvest	Brown rice yield (%)	Head rice recovery (%)	Chalk index determination (%)
H_1	63.477 b	56.422 b	38.497 a
H_2	70.717 a	62.709 a	36.904 b
H_3	69.589 a	62.149 a	36.072 c
CV (%)	4.79	5.79	3.63
LSD $_{(0.05)}$	2.756	2.962	1.141
F-test	**	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. **, indicate 1% level of probability; WAF: weeks after flowering; H_1= 3 WAF, H_2= 4 WAF, H_3= 5 WAF

Table-4. Combination effect of biochar levels, drought stress and time of harvest on the milling traits of BRRI dhan50

Combina-tions	Brown rice yield (%)	Head rice recovery (%)	Chalk index determination (%)
$B_1D_1H_1$	56.557 f	50.557 d	43.067 a
$B_1D_1H_2$	64.317 de	56.647 c	42.547 ab
$B_1D_1H_3$	64.757 c-e	58.207 c	41.607 a-c
$B_1D_2H_1$	63.557 e	57.107 c	40.757 bc
$B_1D_2H_2$	65.547 c-e	59.017 c	39.657 cd
$B_1D_2H_3$	63.247 e	57.017 c	37.887 d
$B_2D_1H_1$	64.547 de	57.607 c	38.057 d
$B_2D_1H_2$	75.227 ab	66.667 ab	35.207 e
$B_2D_1H_3$	70.107 bc	62.007 bc	33.347 ef
$B_2D_2H_1$	69.247 cd	60.417 c	32.107 fg
$B_2D_2H_2$	77.777 a	68.507 a	30.207 g
$B_2D_2H_3$	80.247 a	71.367 a	31.447 fg
CV (%)	4.79	5.79	3.63
LSD $_{(0.05)}$	5.513	5.925	2.281
F-test	*	*	*

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. *, indicates 5% level of probability; B_1 = (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}; D_1= At reproductive stage, D_2= At grain filling stage; H_1= 3 weeks after flowering (WAF), H_2= 4 weeks after flowering (WAF) and H_3= 5 weeks after flowering (WAF)

iv) *Amylose content*

Higher amylose content was recorded in B_2 (27.380 %) and D_2 (27.223 %) compared to B_1 (25.900 %) and D_1 (26.057 %), respectively indicating significant effects due to biochar **(Table 5)** and drought stress levels **(Table 6).** Data on harvesting time showed highest amylose content in H_3 (27.277 %) on par with H_2 and lowest was recorded in H_1 (25.999 %). Interaction effect was significant and the highest amylose content was found from $B_2D_2H_3$ (29.567 %) and $B_2D_2H_2$ which were at par **(Table 8)**, $B_1D_1H_1$ showed lowest value (25.017 %).

v) *Protein Content*

Biochar levels, drought stress and harvesting time had significant effect on protein content. **(Tables 5 to 8).** The highest protein content was found in B_2 (7.833 %), D_2 (7.795 %) and H_3 (7.726 %) and it was lowest in B_1 (7.243 %), D_1 (7.281 %) and H_1 (7.246 %). A significant interaction effect was found among application of biochar, drought and harvesting time on the protein content **(Table 8)**. The highest protein content was found from $B_2D_2H_3$ (8.9067 %) followed by $B_2D_2H_2$ while the lowest was in $B_1D_1H_1$ (7.0167 %) on par with $B_1D_1H_2$.

Table-5. Effect of biochar levels on the amylose and protein content of BRRI dhan50

Biochar levels	Amylose content (%)	Protein content (%)
B_1	25.900 b	7.243 b
B_2	27.380 a	7.833 a
CV (%)	3.73	4.21
LSD $_{(0.05)}$	0.686	0.219
F-test	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. **, indicate 1% level of probability; B_1 = (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}

Table-6. Effect of drought stress on the amylose and protein content of BRRI dhan50

Drought stress	Amylose content (%)	Protein content (%)
D_1	26.057 b	7.281 b
D_2	27.223 a	7.795 a
CV (%)	3.73	4.21
LSD $_{(0.05)}$	0.686	0.219
F-test	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. **, indicate 1% level of probability; D_1= At reproductive stage, D_2= At grain filling stage

Table-7. Effect of harvesting time on the amylose and protein content of BRRI dhan50

Time of harvest	Amylose content (%)	Protein content (%)
H_1	25.999 b	7.246 b
H_2	26.644 ab	7.641 a
H_3	27.277 a	7.726 a
CV (%)	3.73	4.21
LSD $_{(0.05)}$	0.840	0.268
F-test	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. **, indicate 1% level of probability. H_1= 3 weeks after flowering (WAF), H_2= 4 weeks after flowering (WAF) and H_3= 5 weeks after flowering (WAF)

Table-8. Combination effect of biochar levels, drought stress and time of harvest on the amylose and protein content of BRRI dhan50

Combina-tions	Amylose content (%)	Protein content (%)
$B_1D_1H_1$	25.017 c	7.0167 d
$B_1D_1H_2$	25.437 bc	7.1067 d
$B_1D_1H_3$	25.887 bc	7.2567 cd
$B_1D_2H_1$	26.087 bc	7.1867 cd
$B_1D_2H_2$	26.227 bc	7.5367 cd
$B_1D_2H_3$	26.747 b	7.3567 cd
$B_2D_1H_1$	26.887 b	7.2467 cd
$B_2D_1H_2$	26.207 bc	7.6767 c
$B_2D_1H_3$	26.907 b	7.3867 cd
$B_2D_2H_1$	26.007 bc	7.5367 cd
$B_2D_2H_2$	28.707 a	8.2467 b
$B_2D_2H_3$	29.567 a	8.9067 a
CV (%)	3.73	4.21
LSD $_{(0.05)}$	1.680	0.537
F-test	*	*

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. *, indicates 5% level of probability; B_1 = (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}; D_1= At reproductive stage, D_2= At grain filling stage; H_1= 3 weeks after flowering (WAF), H_2= 4 weeks after flowering (WAF) and H_3= 5 weeks after flowering (WAF)

vi) Chalkiness of endosperm

Visual detection of kernel reported that, biochar, drought and time of harvest influenced chalkiness of rice kernel **(Table 9)**, which is a significant trait for marketing standard of aromatic rice. White center chalk is only allowed for market sale while others are generally discarded. In the present study, $B_2D_2H_3$, $B_2D_2H_2$ and $B_2D_2H_1$ treatment combinations showed the significant effect of biochar application, drought stress imposed at grain filling stage and harvesting the grains at 3-5 weeks after flowering that resulted in the white center chalky endosperm.

vii) Aroma (Retronasal-by nose)

Random panel test of aroma indicated that, biochar, drought and time of harvest also influenced the aroma of rice kernel **(Table 9).** The application of biochar along with drought stress at grain filling stage and harvesting 3-5 weeks after flowering resulted in higher 2-AP content, the precursor of the grain aroma. Stronger aroma was found from $B_2D_2H_{3,}$ $B_2D_2H_{2,}$ $B_2D_2H_1$ and $B_2D_1H_3$ treatment combinations.

viii) Taste (Orthonasal-by mouth)

Cooking test results of grain also revealed similar trend and $B_2D_2H_{3,}$ $B_2D_2H_2$ and $B_2D_2H_1$ treatment combinations resulted in sweet cooked rice preferred for market sale. Thus, it was evident that application of biochar along with drought stress imposed at grain filling stage and harvesting the grains at 3-5 weeks after flowering gave the sweet kernel after cooking.

Table-9. Combination effect of biochar levels, drought stress and time of harvest on the chalkiness, aroma and taste of BRRI dhan50

Combina-tions	Chalkiness of endosperm	Aroma (Retrona-sal-by nose)	Taste (Orthona-sal-by mouth)
$B_1D_1H_1$	White back	NS	Sour
$B_1D_1H_2$	White back	MS	Sour
$B_1D_1H_3$	White back	MS	Sour
$B_1D_2H_1$	White back	NS	Salty
$B_1D_2H_2$	White back	MS	Salty
$B_1D_2H_3$	White back	OTB	Sour
$B_2D_1H_1$	White belly	OTB	Salty
$B_2D_1H_2$	White belly	OTB	Salty
$B_2D_1H_3$	White belly	SS	Salty
$B_2D_2H_1$	White center	SS	Sweet
$B_2D_2H_2$	White center	SS	Sweet
$B_2D_2H_3$	White center	SS	Sweet

B_1 = (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}; D_1= At reproductive stage, D_2= At grain filling stage; H_1= 3 WAF, H_2= 4 WAF, H_3= 5 WAF; Strongly scented (SS); mild scented (MS); non-scented (NS) and other than basmati (OTB).

ix) Soil status

The pre-planting and post-harvesting soil analysis revealed that application of biochar increased the status of organic carbon **(Table 10)** The cultivation of aromatic rice with normal puddling cultivation system in pots along with combination of biochar increased the amount of organic carbon content in post-harvest soil. The puddled condition normally increased the amount of atmospheric carbon as methane form, while biochar application improved the porosity of soil due to presence of more organic carbon in soil. The emitted methane was also sequestrated as organic carbon in the increased porus particles of soil. Lowering of pH followed by a lower solubility of SOC (soil organic carbon) will therefore decrease the ability of microbes to utilize energy and nutrients of SOC leading to decrease in decomposition and biomass production. Bot and Benites (2005) reported that H+ ions bind to COO-sites of humus at decreasing pH value thereby reducing the cation exchange capacity. This resulted in post-harvest increase of SOC. It has also been hypothesized that biochar may increase microbial biomass in soil by the complexation of SOM (soil organic matter) with biochar particles and yet simultaneously induce the 'negative priming' of native soil carbon mineralization (Woolf and Lehmann, 2012).

Table 10. Soil data, before transplanting of seedlings and after harvesting of crop

Treat-ments	Before transplanting of seedlings		After harvesting of crop	
	pH	Organic carbon (%)	pH	Organic carbon (%)
$B_1D_1H_1$	6.3	0.42	6.2	0.44
$B_1D_1H_2$	6.2	0.41	6.1	0.40
$B_1D_1H_3$	6.1	0.29	5.9	0.30
$B_1D_2H_1$	6.5	0.37	6.4	0.36
$B_1D_2H_2$	6.5	0.24	6.0	0.25
$B_1D_2H_3$	6.7	0.36	6.1	0.38
$B_2D_1H_1$	6.5	0.41	4.5	0.71
$B_2D_1H_2$	6.4	0.32	4.6	0.77
$B_2D_1H_3$	6.6	0.41	4.6	0.81
$B_2D_2H_1$	6.7	0.31	4.5	0.89
$B_2D_2H_2$	6.5	0.39	4.5	0.95
$B_2D_2H_3$	6.4	0.37	4.3	0.93

B_1 = (Control) 0.0 t ha^{-1}, B_2 = 5.0 t ha^{-1}; D_1= at reproductive stage, D_2= at grain filling stage; H_1= 3 WAF, H_2= 4 WAF, H_3= 5 WAF

Conclusions

Overall, in the present study, application of biochar @ 5tha^{-1} along with drought stress imposed at grain filling stage and crop harvested 5 weeks after flowering showed the best result for milling traits and aroma of fragrant rice (BRRI dhan 50). However, in case of chalk index and no biochar application, drought stress at reproductive stage and crop harvested 3 weeks after flowering gave the best result.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Response of varieties under high and low input management in semi-dry rice ecosystem

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Abstract

A field experiment was conducted during *Rabi*, 2020-21 at Tamil Nadu Agricultural University, Coimbatore, to study the response of varieties with high and low nutrient levels under semi-dry rice system. The experiment was laid out in split plot design with varieties in main plot *viz.*, Anna 4, PMK 3, TKM 12, CO 51, CO 53 and three graded nutrient levels in sub-plot *viz.*, 75 per cent recommended dose of fertilizer (60:20:30 kg NPK/ha), 100 per cent recommended dose of fertilizer (75:25:37.5 kg NPK/ha) and 125 per cent recommended dose of fertilizer (90:30:45 kg NPK/ha). The results revealed that, among the different varieties evaluated under semi-dry ecosystem, CO 53 showed higher grain yield on par with Anna 4. Among the nutrient levels, 125 per cent recommended dose of fertilizer (RDF) recorded higher grain yield at par with 100 per cent RDF. From this study it can be concluded that, short duration variety CO 53 and Anna 4 is best suitable under semi-dry system with 100 per cent recommended dose of fertilizer (75:25:37.5 kg NPK/ha) in Tamil Nadu.

Keywords: Semi-dry rice, varieties, nutrient levels, root length, yield, economics

Introduction

Rice is consumed by more than half of the world's population and India is the second largest producer of rice in the world and it is the major cereal crop of the country. Most of rice is grown by transplanting seedlings into puddled soils and is then kept flooded for most of the growing season. However, transplanting consumes large amount of labour, water and energy which are gradually becoming scarce thereby necessitating the need to shift to direct seeded rice (DSR) systems. In India, area under semi-dry rice cultivation is 17.53 m ha and production is around 36.48 per cent. Semi-dry direct seeded system is a method of cultivation of rice wherein seeds are sown in ploughed dry soil before monsoon rains similar to aerobic rice. When the monsoon becomes active the field is impounded with rainwater, canal water or borewell water and rice is continued as wet - crop. It is most common in areas where, due to late release of water timely transplantation cannot be done. This cuts down the initial water consumption up to 30 per cent by avoiding raising of seedlings in nursery, puddling and transplanting under puddled soil. Semi-dry rice system also reduces the cost of cultivation by avoiding the preparatory operations like puddling, levelling, bund formation and transplanting. In India, Tamil Nadu state has some area under rainfed and semi-dry rice with a vast scope of growing rice under aerobic conditions. The semi-dry rice is a contingent plan to command areas, anticipating the release of water in rice crop which can be established under rainfed conditions up to maximum of 45 days' duration of crop (Bhushan *et al.*, 2007). Field is converted into wet condition on receipt of canal water and nutrient management is decided according to the period of irrigation (Bouman and Lampayan, 2009). The new concept of aerobic rice entails the use of nutrient responsive different cultivars that are initially adapted to aerobic environment aiming at 70-80 % higher yields (Kumar and Ladha, 2011). Semi-dry rice cultivation refers to rice which is sown on dry seed bed as an upland crop taking advantage of monsoon rains. At 4th and 5th leaf stage, when the rainfall intensifies or sufficient water is released from the tank or irrigation projects, the field is converted into wetland rice. Nitrogen and potassium are the key nutrients which frequently limit the rice production. In puddled rice system, the nitrogen use efficiency is approximately 30 per cent where as in upland irrigated or rainfed rice, nitrogen use efficiency would be 40 to 60 per cent (Raj *et al.,* 2014). Nitrogen and potassium are the main nutrients determining rice yield, due to their role in the photosynthesis, biomass accumulation and spikelet formation (Hasegawa *et al*., 1994: Yoshida *et al.,* 2006). Many factors are responsible for increasing yield and quality of crops. Among these, proper and balanced application of fertilizers is one of the most important factors contributing towards higher productivity (Raj *et al.*, 2014). With this background, an experiment was conducted to study the response of varieties under high and low input management in semi-dry rice ecosystem.

Materials and Methods

A field experiment was conducted during *Rabi*, 2020-21 in the department of Rice farm situated at 11^0 N latitude and 77^0 E longitude at Tamil Nadu Agricultural University, Coimbatore. The soil of the experimental field was clay in texture with a pH of 8.22, organic carbon (0.45 %), low in available nitrogen (228 kg/ha), medium in available phosphorus (21 kg/ha) and high in available potassium (483 kg/ha). The experiment was laid out in split plot design with three replications. The treatments comprised of five varieties in main plot *viz.*, Anna 4, PMK 3, TKM 12, CO 51, CO 53 and three graded nutrient levels in sub-plot *viz.*, 75 per cent recommended dose of fertilizer (60:20:30 kg NPK/ha), 100 per cent recommended dose of fertilizer (75:25:37.5 kg NPK/ha) and 125 per cent recommended dose of fertilizer (90:30:45 kg NPK/ha). Entire dose of phosphorus was applied as basal whereas N and K were applied in three splits at 20-25, 40-45 and 60-65 days after germination. Under semi-dry rice system, seeds were sown in un-puddled soil and the crop was maintained with receiving of the rainfall, while after 45^{th} day the field was converted into wet condition. Recommended pre-emergence herbicide application of pendimethalin @ 1.0 kg/ha was done 5 days after sowing on the day of receipt of soaking rain followed by one hand weeding at 30-35 days after sowing. The crop was harvested when plants turned yellow and attained maturity. Growth parameters on root length were recorded by collecting plants in sampling row using digging fork, and maximum root length was measured after careful washing of roots. Plants collected for root length were also used for recording root volume and root dry weight. The root volume hill^{-1} was measured by water displacement method and expressed in cm^3 hill^{-1}. The root dry weight was measured by oven dry weight basis and expressed as g hill^{-1}. The border rows of all around the plots were harvested first and then the plants from the net plots were harvested and threshed. The yield was expressed in kg/ha and the grain weight was expressed in 14 % moisture basis (Yoshida *et al*.,1976). In economic analysis, the benefit cost ratio was worked out by using the formula of ratio between the gross return (Rs/ha) and total cost of cultivation (Rs/ha). The data were statistically analyzed as per the method suggested by Gomez and Gomez (1984).

Results and Discussion

Growth attributes

Rice varieties exhibited significant influence on root length, root volume and root dry weight under different nutrient levels in semi-dry rice ecosystem. Among the rice varieties, CO 53 and Anna 4 exhibited higher root length (14.9 and 14.3 cm) and root volume (32.8 and 31.2 g/cc), respectively. The root dry weight was also higher in CO 53 (5.3 g/hill) and Anna 4 (5.2 g/hill) compared to other varieties evaluated under semi-dry system. The varieties with short duration, short stature, intermediate plant height, long roots, rapid shoot and root growth, long mesocotyles and coloeoptiles, have the ability to withstand stress during early stages (Farooq *et.al.,* 2011). Among the nutrient levels, 125 per cent recommended dose of NPK level exhibited higher root length, root volume and root dry weight on par with 100 per cent recommended dose of NPK level **(Figure 1 & 2, Table 1).**

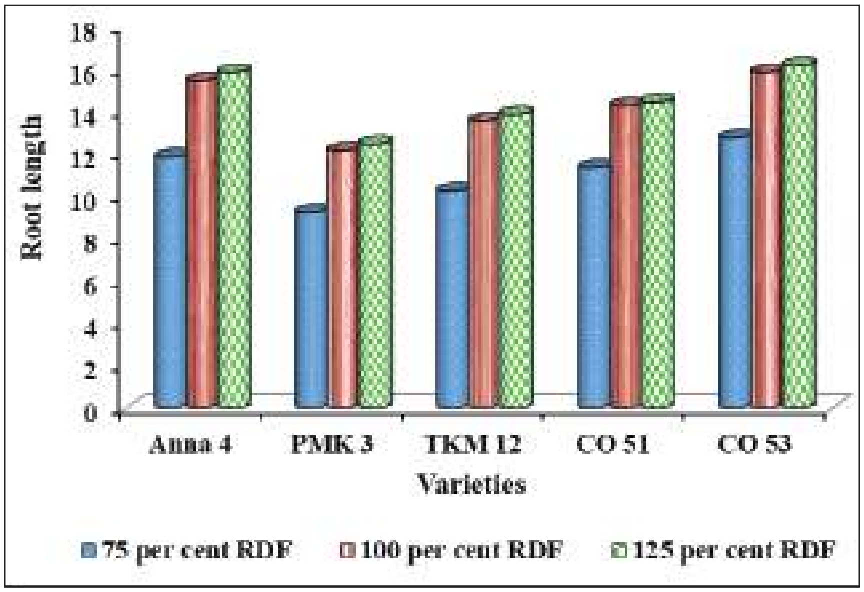

Figure 1. Response of varieties and nutrient levels on root length (cm) of rice under semi dry ecosystem

Table 1. Response of varieties and nutrient levels on root volume (g/cc) of rice under semi-dry system

Treatments	Anna 4	PMK 3	TKM 12	CO 51	CO 53	Mean
75 per cent RDF (60:20:30 kg NPK/ha)	24.7	21.4	20.3	24.4	25.2	23.2
100 per cent RDF (75:25:37.5 kg NPK/ha)	34.2	27.1	25.6	33.1	36.5	31.3
125 per cent RDF (90:30:45 kg NPK/ha)	34.6	27.7	26.2	33.7	36.8	31.8
Mean	**31.2**	**25.4**	**24.0**	**30.4**	**32.8**	
	N	**V**	**N x V**	**V x N**		
S.Ed	0.8	0.7	1.4	1.5		
CD (0.05)	1.8	1.6	3.1	3.2		

(*RDF – Recommended Dose of Fertilizer)

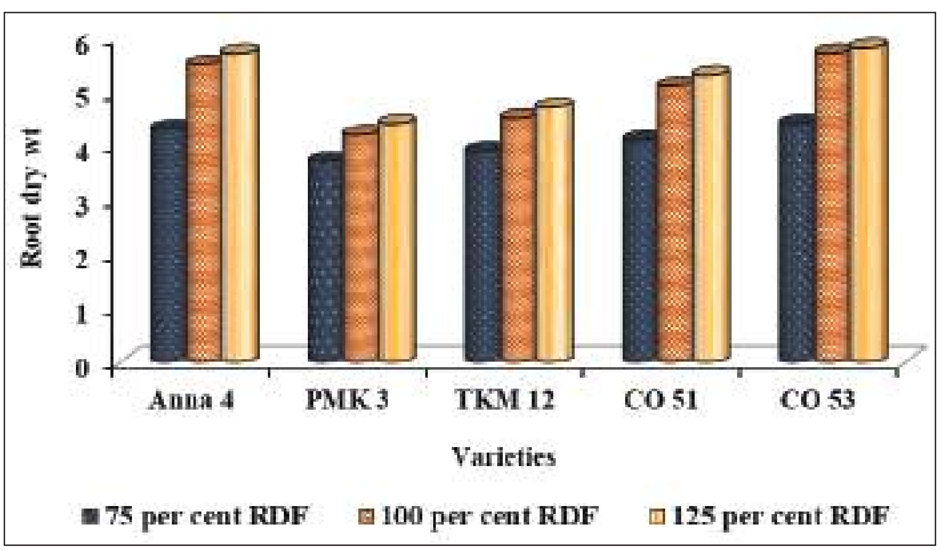

Figure 2. Response of varieties and nutrient levels on root dry weight (g) of rice under semi dry system

Table 2. Response of varieties and nutrient levels on number of productive tillers/m^2 of rice under semi-dry system

Treatments	Anna 4	PMK 3	TKM 12	CO 51	CO 53	Mean
75 per cent RDF (60:20:30 kg NPK/ha)	243	188	206	213	221	214
100 per cent RDF (75:25:37.5 kg NPK/ha)	338	287	304	311	326	313
125 per cent RDF (90:30:45 kg NPK/ha)	342	294	317	324	340	322
Mean	**308**	**256**	**276**	**283**	**296**	
	N	V	N x V	V x N		
S.Ed	8	7	13	12		
CD (0.05)	16	14	24	22		

Higher number of productive tillers/m^2 was observed in Anna 4 (308) and was at per with CO53 **(Table 2).** Among the different varieties evaluated under semi-dry ecosystem, CO 53 showed higher grain yield (4774 kg/ha) and was on par with Anna 4 **(Table 3).** The varieties which are early and with rapid growth rate, higher tiller number, high biomass accumulation at early stages and erect leaves have increased crop growth rate during the reproductive phase and prolonged ripening phase. They also exhibit, resistance to lodging and more grains in primary panicle contributing to their better performance under semi-dry ecosystem (Farooq *et.al.*, 2011). The higher grain yield is also because of higher number of panicles and lower sterility percentage (Jagmohan Kaur and Avtar Singh, 2017). Among the nutrient levels, 125 per cent RDF recorded higher grain yield of 4588 kg/ha which was on par with 100 per cent RDF (4516 kg/ha, **Table 3**).

Table 3. Response of varieties and nutrient levels on grain yield (kg/ha) of rice under semi-dry system

Treatments	Anna 4	PMK 3	TKM 12	CO 51	CO 53	Mean
75 per cent RDF (60:20:30 kg NPK/ha)	4036	3071	3322	3856	4122	3681
100 per cent RDF (75:25:37.5 kg NPK/ha)	4866	3836	4127	4685	5067	4516
125 per cent RDF (90:30:45 kg NPK/ha)	4921	3922	4233	4732	5132	4588
Mean	**4608**	**3610**	**3894**	**4424**	**4774**	
	N	**V**	**N x V**	**V x N**		
S.Ed	135	130	152	173		
CD (0.05)	280	265	485	436		

Economics

Variety CO 53 under 100 per cent recommended dose of fertilizer regime yielded higher net return of Rs. 38,005/- with benefit: cost ratio of 2.00 followed by the variety Anna 4 with net return of Rs. 34,990/- and benefit: cost ratio of 1.91**(Table 4 & Figure 3).** Application of 125 per cent RDF resulted in lesser net return and B:C ratio compared to 100 per cent RDF.

Table 4. Response of varieties and nutrient levels on economics of rice cultivation under semi-dry system

Treatments	Gross return (Rs./ha)					BCR				
	Anna 4	PMK 3	TKM 12	CO 51	CO 53	Anna 4	PMK 3	TKM 12	CO 51	CO 53
75 per cent RDF	60540	46065	49830	59340	61830	1.64	1.25	1.35	1.60	1.67
100 per cent RDF	72990	57540	61905	71775	76005	1.91	1.51	1.63	1.88	2.00
125 per cent RDF	73815	58830	63495	72480	76980	1.89	1.50	1.62	1.86	1.97

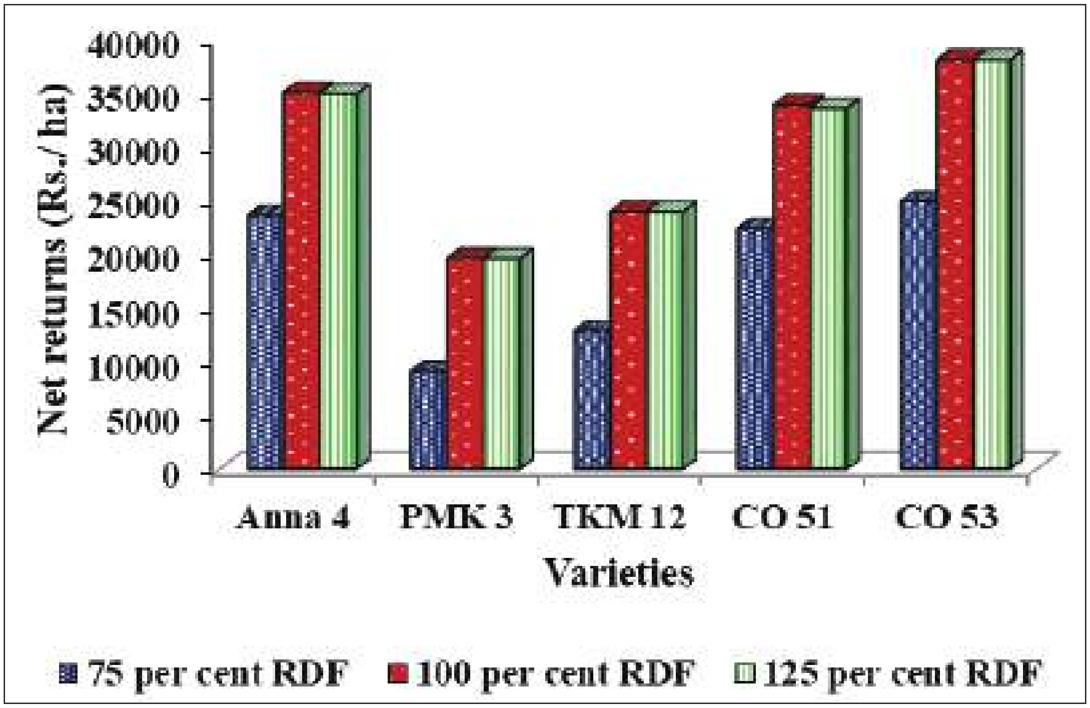

Figure 3. Response of varieties and nutrient levels on net retiurns (Rs./ha) of rice cultivation under semi dry system

Conclusion

From this study it can be concluded that, short duration variety CO 53 and Anna 4 are best suitable under semi-dry system and nutrient level of 100 per cent recommended dose of fertilizer (75:25:37.5 kg NPK/ ha) is recommended for semi-dry rice cultivation in Tamil Nadu.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Up-scaling of water saving technologies in rice cultivation under corporate social responsibility scheme

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Abstract

Field demonstrations were carried out in 25 locations each separately in Villupuram district of Tamilnadu for upscaling water saving technology in rice cultivation like System of Rice Intensification (SRI) and Alternate Wetting and Drying Irrigation(AWDI). The bio-metric observation data was recorded in the earmarked area in the demonstration field plot and the computed average mean data was used for analysis. In the demonstrations, the total water requirement, quantity of water required to produce one kilogram of rice and number of irrigations were significantly less in SRI compared to conventional planting system. There was water saving of 350 mm recording 29.16 percentage. Similarly, AWDI demonstrations revealed that, AWDI saved 270-350 mm more water per hectare than the normal irrigation system. Increase in the grain yields obtained with water saving made the farmers confident on these water saving technologies.

Keywords: Rice crop,water saving technology, up-scaling

Introduction

Rice is the principal food crop grown in 29 districts of Tamilnadu state. Being the major consumer of water, the water use efficiency of growing rice crop is low compared to other field crops. The total area on an average under rice cultivation in Tamilnadu is 17 to18 lakh hectares. Though the modifications in rice cultivation system are available for mitigating the intermittent drought, the popularisation of these technologies is the need of the hour for conserving the precious irrigation water and to sustain the rice productivity. The promising technologies on water saving in rice like System of Rice Intensification (SRI) and Alternate Wetting and Drying Irrigation(AWDI) were advocated to the farmers on corporate social responsibility basis to upscale and popularise the techniques among poor land holding farmers and thereby improve the livelihood of the farmers in rice growing locations of Villupuram district of Tamilnadu.

Methodology

Up scaling of promising Technologies (SRI&AWDI)

1. The System of Rice Intensification (SRI)

The System of Rice Intensification, known as SRI in rice cultivation, can reduce water requirements, increase land productivity, and promote less reliance on artificial fertilizers, pesticides, herbicides, and other agrochemicals, all while buffering against the effects of climate change and reducing greenhouse gases. The methodology is based on principles that interact with each other like: early, quick and healthy plant establishment, reduced plant density, improved soil conditions through enrichment with organic matter and reduced and controlled water application. Recommended management practices for SRI under irrigated conditions are transplanting single seedlings (one plant per hill) that are 2 - 3 leaf-stage usually 14-15 days' old minimizing the transplanting shock and widely spaced in a square grid pattern of 25x25 cm accommodating 16 plants per metre square.

Soil: The soil is enriched with organic matter to improve soil structure, nutrient and water holding capacity, and favour soil microbial development.

Water: Only a minimum amount of water is applied during the vegetative growth period. 1-2 cm layer depth of water is introduced into rice plot followed by allowing the rice field to dry until cracks become visible, at that point of time, a thin layer of water is introduced by alternate wetting and drying until flowering stage. At flowering, a saturated layer of water is maintained till the grain filling period and water drained in the rice field 2-3 weeks before harvest.

Nutrients: As soils are improved through organic matter additions, many nutrients become available to the plant from the organic matter. Additionally, the soil is also able to hold more nutrients in the rooting zone and release them when the plants need them.

Weeds: While avoiding flooded conditions in the rice fields, weeds are to be kept under control at an early stage. A rotary hoe - a simple, inexpensive, mechanical push weeder is most often used starting at 10 days after transplanting, repeated ideally every 7-10 days until the canopy coverage of the crop. The weeder has multiple functions like incorporating the weeds into the soil, after decomposing the nutrients are recycled. The procedure also provides a light superficial tilth and aerates the soil. It stimulates root growth by root pruning and makes nutrients available to the plant system. The process also distributes water across the plot, contributing to continuous levelling of the plot and eliminating dry water patches in the field that could create anaerobic conditions for the rice plants. The use of the weeder contributes to homogeneous field conditions, creating a uniform crop stand and leading to increased yields.

2. Alternate Wetting and Drying Irrigation (AWDI)

Alternate Wetting and Drying Irrigation (AWDI) is a water-saving technology that farmers can apply to reduce their irrigation water use in rice fields without decreasing yield. In AWD, irrigation water is applied, a few days after the disappearance of the ponded water. Hence, the field is alternately flooded and non-flooded. The number of days of non-flooded soil between irrigations can vary from one to more than ten days depending on a number of factors such as soil type, weather and crop growth stage. A practical way to implement AWD safely is by using a 'field water tube' ('pani pipe') to monitor the water depth on the field. After irrigation, the water depth will gradually decrease. When the water level in the water pipe has dropped to about 15 cm below the surface of the soil, irrigation should be applied to re-flood the field to a depth of about 2.5 cm. One week before and a week after flowering, the field should be kept to a depth of 2.5 cm as needed. After flowering period, the water level can be allowed to drop again to 15 cm below the soil surface before re-irrigation. AWD can be started a few weeks (1-2 weeks) after transplanting. When more weeds are present, AWD should be postponed for 2-3 weeks to assist suppression of the weeds by the ponded water

The field **water tube (*Pani pipe*)**: The field water tube is made up of 30 cm long plastic pipe and should have a diameter of 10-15 cm so that the water table is easily visible, and also it is easy to remove soil inside. Perforate the tube with many holes on all sides, so that water can flow readily in and out of the tube. Hammer the tube into the soil, so that 15 cm protrudes above the soil surface. Take care not to penetrate through the bottom of the plough pan. Remove the soil from inside the tube so that the bottom of the tube is visible.

Results and Discussion

Field demonstrations were carried out in 25 locations each separately in Villupuram district for upscaling water saving technology in rice cultivation like SRI and AWDI. In the field demonstrations conducted, plant biometric observations were recorded and water saving components computed.

In SRI demonstrations, the conventional planting system recorded water requirement from 1200 - 1390 mm compared to 850 mm -1050 mm of water requirement in SRI. Quantity of water required to produce one kilogram of rice was 2200 - 2950 litres in conventional planting compared to 1440-1880 litres in SRI system. The number of irrigations recorded were 24-30 in conventional planting and 15-24 irrigations **(Table 1)** in SRI. There was water saving of 350 mm per hectare.

In AWDI demonstrations, the normal irrigation system recorded water requirement from 1200 - 1350 mm compared to 750 mm - 1050 mm of water requirement in AWDI. Quantity of water required to produce one kilogram of rice was 2300 - 2900 litres in normal irrigation system compared to 1300-1900 litres in AWDI. The number of irrigations recorded were 24-30 in normal irrigation system and 15-24 irrigations in AWDI **(Table 2).** There was water saving of 270 to 350 mm per hectare.

Outcome of the project

- ❖ During the conduct of the CSR programme, the farmers realized the ill effect of flooding and the positive factors of alternate wetting and drying.
- ❖ The water saving through adoption of the technologies helped the farmers to expand additional area under rice cultivation.
- ❖ Through introduction of these technologies, inadequacy of labour and non-availability of labours for field could be managed easily.
- ❖ Increase in the grain yields obtained made the farmers confident on the water saving technologies.
- ❖ The rice growing system in the demonstrated areas could be modified completely resulting in considerable quantity of water saving.
- ❖ The concept of flooding would be completely eliminated from the minds of rice farmers.

Table.1. Water productivity in conventional rice planting and system of rice intensification

Sl. No	Name of the Farmer	No. of Irrigation		WR (m^3)		Water Productivity (kg/m^3)		Litre of water /kg of grain		Rice Variety
		Conv	SRI	Conv	SRI	Conv	SRI	Conv.	SRI	
1.	Th.G.Nagarajan KilVayalamur	26	19	13000	9750	0.40	0.65	2471	1537	ADT 37
2.	Th.S.Durai,Kedar Kedar	24	17	12000	8500	0.41	0.67	2439	1483	TKM 13
3.	Th.P.Prabhagar Kalladikupam	25	19	12500	9750	0.40	0.63	2485	1585	ADT 37
4.	Th.N.Ganavel, Kedar	27	20	13500	10250	0.34	0.53	2903	1880	ADT 45
5.	Th.R.Duraikkannu Veeramur	26	19	13000	9750	0.41	0.64	2411	1560	ADT 39
6.	Th.M.Antonysamy Kilvayalamur	27	20	13500	10250	0.38	0.59	2626	1694	BPT5204
7.	Tmt.E.Dhanam Vairapuram	26	18	13000	9000	0.42	0.75	2342	1333	ADT 37
8.	Th.V.Purushotaman KilVayalamur	23	19	12500	9750	0.45	0.67	2200	1488	ADT 37
9.	Th.V.Abaranji KilVayalamur	26	19	13000	9750	0.42	0.64	2385	1547	ADT 37
10	Th.V.Mayappan KilVayalamur	27	21	13500	10500	0.41	0.62	2495	1622	ADT 37
11.	Th.V.Kumar Vairapuram	24	17	12000	8500	0.42	0.70	2366	1428	ADT 37

Sl. No	Name of the Farmer	No. of Irrigation		WR (m³)		Water Productivity (kg/m³)		Litre of water /kg of grain		Rice Variety
		Conv	SRI	Conv	SRI	Conv	SRI	Conv.	SRI	
12.	Th.V.Murugesan Vairapuram	23	15	12500	9750	0.37	0.57	2688	1747	ADT 45
13.	Tmt.M.Vasantha Vairapuram	26	21	13000	10250	0.38	0.59	2642	1694	ADT 45
14.	Th.G.Elumalai Kilvayalamur	27	19	13500	9750	0.33	0.58	2947	1728	ADT 37
15.	Th.N.Sundharrajan Kongarampondi	26	21	13000	10250	0.36	0.56	2795	1772	ADT 37
16.	Th.V.Narasimman Kongarampondi	24	19	12000	9750	0.43	0.62	2330	1598	ADT 37
17.	Th. M.Krishnan, Marur	27	22	13500	10500	0.38	0.58	2673	1710	ADT 37
18.	Th. N. Nirmala Kilvayalamur	30	24	13700	10250	0.34	0.55	2926	1796	ADT 37
19.	Th.K.Manivannan Melperadikuppam	30	25	12500	8750	0.34	0.64	2941	1557	ADT 37
20.	Th. N. Nagaraj Kilvayalamur	30	26	13900	10200	0.34	0.58	2926	1721	ADT 37
21.	Tmt.M.Aanathi Melperadikuppam	30	24	12000	9000	0.39	0.64	2561	1547	ADT 37
22.	Th. K. Manikkam Kollar	30	24	12800	9900	0.35	0.54	2843	1821	ADT 37
23.	Th.N.Elumalai Aazhiyur	28	24	13500	9750	0.33	0.58	2947	1728	ASD 16
24.	Th.R.Venkatachalam Kilvayalamur	29	24	13000	9500	0.37	0.63	2669	1580	ADT 37
25	Th.N.Mohan Aazhiyur	30	23	12000	8500	0.45	0.69	2222	1440	ADT 37

Table.2. Water productivity in conventional irrigation practice and alternate wetting and drying

Sl. No	Name of the Farmer	No. of Irrigation		Litre of water / kg of grain		Water Productivity (kg/m³)		WR (m³)		Variety
		FP	AWDI	FP	AWDI	FP	AWDI	FP	AWDI	
1.	Th.G.Jayamurthy V.salai	27	19	2523	1619	0.39	0.62	13500	9750	BPT 5204
2.	Th.D.Sridhar Konkrampundi	26	17	2490	1529	0.40	0.65	13000	8950	BPT 5204
3.	Th.M.Elumalai Aralavadi	24	16	2343	1536	0.43	0.66	12000	8300	ADT 37
4.	Th.P.Yoganathan Nemur	23	16	2432	1349	0.41	0.74	13500	8300	ADT 37
5.	Th.V.Chellapan Vairapuram	25	17	2475	1488	0.40	0.67	12500	8500	ADT 37

Sl. No	Name of the Farmer	No. of Irrigation		Litre of water / kg of grain		Water Productivity (kg/m³)		WR (m³)		Variety
		FP	AWDI	FP	AWDI	FP	AWDI	FP	AWDI	
6.	Th.E.Mani, Kedar	24	15	2580	1428	0.40	0.70	12000	7500	ADT 45
7.	Th.B.Dharmadurai Agaramchithamur	28	18	2755	1706	0.38	0.59	14000	9300	ADT 39
8.	Th.P.Shanmugam Vairapuram	25	17	2427	1491	0.41	0.67	12500	8800	ADT 37
9.	Th.D.Ganeshkumar Vairapuram	26	18	2476	1570	0.40	0.64	13000	9250	ADT37
10	Th.G.Viswanathan Kilvayalamur	27	17	2903	1708	0.34	0.58	13500	8750	ADT 37
11.	Th.A. Gnanavel Periyathachur	24	15	2376	1456	0.42	0.68	12000	8100	ADT 37
12.	Th. M. Kaliyamoorthy Navamalmarudhur	28	23	2621	1681	0.38	0.59	13500	9750	CO 51
13.	Th.M. Krishnamorthi Navamalmarudhur	30	24	2475	1681	0.40	0.59	12500	9500	CO 51
14.	Th. M. Arumugam Aliyur	25	18	2549	1757	0.39	0.56	13000	9750	ADT 37
15.	Th. S. Deivanayagam Aliyur	28	22	2626	1666	0.38	0.6	13500	9500	ADT 37
16.	Th. M. Narayanan Aliyur	29	21	2366	1531	0.42	0.65	12000	8500	ADT 37
17.	Th. S.Venkatachalam Aliyur	30	23	2631	1875	0.38	0.53	13500	10500	ADT 37
18.	Th.S.Krishnagovindan Navamalmarudhur	28	23	2330	1725	0.42	0.57	12000	9750	NLR 91
19.	Th. V.Narayanan Aliyur	30	24	2647	1926	0.37	0.51	13500	10500	ADT 37
20.	Th. S.Bathrachalam Aliyur	29	24	2450	1460	0.40	0.68	12500	8400	ADT 37
21.	Th. S. Selvaraj Aliyur	28	22	2376	1586	0.42	0.66	12000	8500	ADT 37
22.	Th. N.Santhakumar NavamalMaruthur	30	23	2325	1741	0.40	0.57	12000	9750	CO 51
23.	Th. D. Prabhu Aliyur	30	22	2450	1710	0.40	0.58	12500	9750	ADT 37
24.	Th.D. Prakash Aliyur	30	23	2637	1853	0.37	0.53	13500	10250	ADT 37
25.	Th.T. Duraikannu Aliyur	28	22	2534	1773	0.39	0.56	13000	9750	ADT 37

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Effect of insecticides on the feeding and fecundity of rice brown planthopper, *Nilaparvata lugens* (Stål)

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Abstract

Stimulatory effect of some insecticides on feeding and reproductive rate of rice brown planthopper *Nilaparvata lugens* (Stål) was investigated in the laboratory experiment during *kharif* 2020 and *rabi*, 2020-21 at RARS, Maruteru, Andhra Pradesh. Brown planthopper excreted significantly higher amount of honeydew on deltamethrin (278.67mm^2) and fipronil (231.17mm^2) treated rice plants. Deltamethrin also resulted in enhancement of reproductive rate of BPH and consequently resulted in resurgence (resurgence ratio>1), whereas the remaining insecticides *i.e*., flubendiamide, chlorantraniliprole (foliar and granular), fipronil, carbofuran and cartap hydrochloride did not influence the reproductive rate of BPH (resurgence ratio<1). Hence, insecticides barring deltamethrin can be used judiciously against insect pests of rice with periodical monitoring for development of resistance and induction of resurgence.

Keywords: Brown planthopper, resurgence, reproductive rate, fecundity, insecticides, feeding rate, rice, honey-dew excretion, *Nilaparvata lugens*

Introduction

Among the insect pests infesting rice, brown planthopper (BPH), *Nilaparvata lugens* (Stal) (Hemiptera: Delphacidae) is considered as the major yield limiting factor in all the rice growing countries both in tropics and temperate regions (Krishnaiah, 2014). Both the nymphs and adults of the BPH suck plant sap from phloem cells resulting in "hopper burn" symptoms and it can cover large circular patches in the rice fields under heavy pest pressure. Besides direct feeding damage, it also serves as vector for rice grassy stunt and rice ragged stunt viruses (Hibino, 1990).

Farmers rely solely on insecticides for the management of planthoppers and almost 50% of the insecticides used in rice are targeted against BPH alone (Reddy *et al*., 2012). But their repeated applications often result in problems such as development of insecticide resistance, residues in the farm produce and environmental contamination. Besides this, insecticides may affect the physiology of the target insect pests directly through stimulation of growth and reproduction or indirectly through the alteration in the nutritional quality of host plant that leads to increased feeding and may result in resurgence of the BPH (Chelliah and Heinrichs, 1980). Application of fipronil significantly increased the quantity of honeydew excreted by BPH (Ling *et al.,* 2009).

Suri *et al.,* (2015) reported that deltamethrin, methyl parathion and quinalphos significantly enhanced the reproductive rate of brown planthopper and consequently resulted in higher resurgence ratio. Synthetic pyrethroids like bifenthrin, cypermethrin, lambda cyhalothrin and deltamethrin resulted in enhancement of fecundity of brown planthopper (227.67, 218.33, 199.00 and 191.00 nymphs' vs 131.00 nymphs in control) and consequently resurgence ratio ranged from 1.18 to 1.74 (Anand Kumar *et al*., 2019). Keeping this in view, the present laboratory study was undertaken to investigate the stimulatory effects of some insecticides that are most frequently being used in rice ecosystem on feeding and reproduction of brown planthopper.

Materials and Methods

A laboratory experiment in completely randomized design (CRD) was conducted in poly-house of the Department of Entomology, Regional Agricultural Research Station (RARS), Maruteru, West Godavari District of Andhra Pradesh during *kharif* 2020 and *rabi* 2020-21.

Brown planthopper (BPH), *Nilaparvata lugens* (Stal) was reared on one month old potted plants of the susceptible rice variety, Taichung Native-1 (TN1) to obtain large number of nymphs and adults of brown planthopper of uniform size and age required for different experiments. Planthopper susceptible rice variety, Swarna (MTU 7029) was used as test variety in the experimentation. The insecticides *viz*., Flubendiamide 20WG, Chlorantraniliprole 18.5SC, Fipronil 5SC, Deltamethrin 2.8EC, Carbofuran 3G, Chlorantraniliprole 0.4G and Cartap hydrochloride 4G including untreated control were used to study their impact on feeding and fecundity of BPH. Emulsions of test insecticides were prepared at recommended doses from the commercial formulations by adding required quantities of water. A pot with one hill represented one replication and each treatment was replicated thrice. Insecticides were applied twice at 20 and 35 days after planting as per the procedure described for resurgence test by Heinrichs *et al*., (1981). The quantity of granular insecticides per pot (surface area of the pot used was 0.025 m^2) was calculated based on the recommended field rate (carbofuran @ 62.5 mg/pot, chlorantraniliprole @ 25 mg/pot and cartap hydrochloride @ 50 mg/pot). The weighed insecticides were incorporated into the soil around the plants in pots with 2 cm standing water and the plants were sprayed with water alone as control.

1) Influence of insecticides on feeding rate of BPH

The relative feeding preference of BPH between insecticide treated and untreated rice plants (control) was assessed indirectly by estimating the amount of honeydew excreted by the adult planthoppers as an indication of the feeding rate (feeding index) adopting the technique developed by Pathak and Heinrichs (1980).

Fifteen days after second spray of foliar insecticides and thirty days after second round application of granular insecticides, tillers of each plant were thinned out retaining only one tiller in each pot. The culm was passed through a hole in the centre of the card board sheet. A polythene sheet was placed on the card board to prevent moisture absorption by the filter paper. Whatman No.1 filter paper was made into 9.00 cm diameter circles with a small hole in the centre and a longitudinal cut from the margin to the centre. These filter paper circles were dipped in bromocresol green solution (2 mg bromocresol green powder/1 ml of ethanol) and allowed to dry for one hour and dipped again till the filter paper circles turned to yellowish orange. The treated filter paper circle was then kept over polythene sheet placed on the card board present at the base of potted plant. Plastic cup containing a hole at the centre was placed in an inverted position over the single potted plant. Two freshly emerged adult female hoppers, pre-starved for two hours were released into the cup through the hole and the hole was plugged with non-absorbent cotton to prevent escape of the insects. The BPH adults were allowed to feed for 24 hours at the base of the stem. The honey-dew droplets excreted by the adults, when come in contact with the filter paper turn into blue spots. The filter paper was removed 24 hours after the commencement of feeding and the total area of the blue spots appeared on each filter paper was measured using Image - J software **(**Rashband, 1997) and expressed as area of honeydew excretion in mm^2 per two females.

2) Influence of insecticides on fecundity of BPH

At 15 days after second spray of foliar insecticides and 30 days after second application of granular insecticides, one pair of adult BPH were released per pot, confined therein for seven days for oviposition and later the insects were removed. To assess the impact of insecticides on reproductive rate (fecundity) of BPH, the nymphs that hatched in each pot were counted daily and removed with aspirator. This process was continued until hatching terminated. The total number of nymphs that hatched on plants treated with insecticides serves as an indirect measure of fecundity of the brown planthopper. Nil mortality of BPH was recorded in all the treatments during resurgence test period.

The resurgence of brown planthopper following the application of each test insecticide was assessed from the comparison of fecundity on the treated and control plants as per the formula given by Heinrichs *et al.*, (1981).

$$\text{\# Resurgence ratio} = \frac{\text{Mean number of BPH nymphs in the treatment}}{\text{Mean number of BPH nymphs in the control}}$$

<1 - No resurgence ; >1 – Resurgence

Statistical Analysis

Data recorded on feeding rate and fecundity were converted into square root transformations and then subjected to analysis of variance technique (ANOVA) (Gomez and Gomez, 1984). The treatment means were compared by Least Significant Difference (LSD) method.

Results and Discussion

1. Feeding Rate (Feeding Index)

Results relating to the effect of insecticides on feeding rate of BPH during *kharif* 2020 are presented in Table 1. Insecticidal treatments had significantly influenced the BPH feeding and honey-dew excretion. The highest feeding rate of BPH was observed on the plants treated with deltamethrin 2.8EC (224 mm^2) and is significantly superior over untreated control (112 mm^2). It was followed by fipronil 5SC (182 mm^2), chlorantraniliprole 18.5SC (132 mm^2) and flubendiamide 20WG (122 mm^2) which were at par with untreated control. Other test insecticides, chlorantraniliprole 0.4G, carbofuran 3G and cartap hydrochloride 4G registered lower feeding rate of 57, 32 and 19 mm^2, respectively in descending order and significantly lower than the untreated check.

During *rabi* 2020-21 also **(Table1),** insecticidal application significantly influenced the BPH feeding and honeydew excretion. Deltamethrin 2.8EC recorded the highest area of honeydew excretion (333.33 mm^2) and was significantly superior to that of untreated check (201.67 mm^2). It was followed by fipronil 5SC (280 mm^2), chlorantraniliprole18.5SC (185 mm^2), flubendiamide 20WG (153.33 mm^2) and carbofuran 3G (133.33 mm^2) which were at par with untreated control. Granular insecticides, chlorantraniliprole 0.4G and cartap hydrochloride 4G registered lower honeydew excretion of 130 and 121.67 mm^2, respectively in descending order and significantly lower than the untreated check.

Table 1. Effect of insecticides on the feeding rate of BPH during *kharif* 2020 and *rabi, 2020*-21

T. No.	Treatment	Dose (ml l^{-1} or kg/ha)	Feeding rate@ (area of honeydew excreted in mm^2)		
			***Kharif* 2020**	***Rabi*, 2020-21**	**Mean**
T_1	Flubendiamide 20 WG	0.25 ml/l	122 (10.98) b	153.33 (12.25) cd	137.70 (11.63) bc
T_2	Chlorantraniliprole18.5 SC	0.3 ml/l	132 (11.47) b	185 (13.38) cd	158.62 (12.47) b
T_3	Fipronil5 SC	2.0 ml/l	182 (13.30) ab	280 (16.72) ab	231.17 (15.18) a
T_4	Deltamethrin 2.8 EC	1.0 ml/l	224 (14.87) a	333.33 (18.21) a	278.67 (16.67) a
T_5	Carbofuran 3G	25.0 kg/ha	32 (5.61) cd	133.33 (11.51) cd	82.44 (9.06) d
T_6	Chlorantraniliprole 0.4 G	10.0 kg/ha	57 (7.47) c	130 (11.38) d	93.74 (9.68) cd
T_7	Cartap hydrochloride 4G	20.0 kg/ha	19 (4.36) d	121.67 (11.00) d	70.42 (8.37) d
T_8	Untreated control	Water spray	112 (10.55) b	201.67 (14.18) bc	156.83 (12.51) b
F test			**Sig.**	**Sig.**	**Sig.**
LSD (0.05)			**2.74**	**2.78**	**2.08**
CV (%)			**16.12**	**11.87**	**10.10**

*Mean of three replications; figures in parentheses are square root transformed values.
@ by 2 adult BPH /24 hours
In a column, means followed by a common letter are not significantly different by LSD (P=0.05)

The mean data of two seasons (*kharif*, 2020 and *rabi*, 2020-21) revealed that, deltamethrin 2.8EC (278.67 mm^2) and fipronil 5SC (231.17 mm^2) registered higher feeding rate of BPH and is significantly superior to untreated control (156.83 mm^2). This was followed by chlorantraniliprole 18.5SC (158.62 mm^2) and flubendiamide 20WG (137.70 mm^2) which were at par with untreated control. Rest of the granular insecticides, chlorantraniliprole 0.4G (93.74 mm^2), carbofuran 3G (82.44 mm^2) and cartap hydrochloride 4G (70.42 mm^2) registered lower honeydew excretion of BPH, respectively in descending order which are significantly lower than the untreated check.

Insecticides are known to have stimulatory or inhibitory influences on feeding of planthoppers in rice. Higher feeding of brown planthopper on deltamethrin and fipronil treated plants as reported in honeydew test might be due to the increased levels of sugars and free amino acids in treated plants compared to untreated rice plants which needs to be confirmed through biochemical analysis of leaf sheaths for sugars and amino acids. Higher feeding of BPH on deltamethrin in the present studies are in agreement with the observations of Chelliah and Heinrichs (1980); Raman and Uthamasamy (1983) and Yi and Choi (1986), who also reported increased feeding rate of BPH on TN1 rice plants treated with deltamethrin, methyl parathion, diazinon, quinalphos, cypermethrin, fenthion and permethrin over the control. Suri and Singh (2009) also reported that methyl parathion, deltamethrin, quinalphos and imidacloprid applied to potted rice plants resulted in enhancement of feeding of whitebacked planthopper. Enhanced feeding of BPH on fipronil treated rice plants is supported by Ling *et al.*, (2009).

2. Reproductive rate (Fecundity) of BPH

Data on reproductive rate of BPH during first season, *kharif* 2020 revealed that insecticides significantly influenced reproductive rate of BPH adults when they were allowed to feed and oviposit on the insecticide treated plants **(Table 2).** The highest reproductive rate of BPH was observed on deltamethrin 2.8EC with 107 nymphs emerged per one pair of adult hoppers and was superior over untreated control (68 nymphs). It was followed by cartap hydrochloride 4G, carbofuran 3G, and flubendiamide 20WG treated plants with 84, 65.33 and 56.67 nymphs emerged per one pair of adult hoppers, respectively and on par with untreated control. While, chlorantraniliprole 18.5SC, chlorantraniliprole 0.4G and fipronil 5SC recorded significantly lower fecundity compared to control.

Resurgence ratio of BPH feeding on deltamethrin 2.8EC was 1.57 indicating the risk associated with the use of this insecticide leading to failure in control of the planthoppers. Other test insecticides recorded a resurgence ratio of less than one.

During second season, *Rabi* 2020-21, the highest reproductive rate of BPH was noticed in deltamethrin 2.8EC with 98.33 nymphal emergence per one pair of adult hoppers and was significantly superior to untreated control (57.00 nymphs). Other treatments, *viz*., flubendiamide 20WG, chlorantraniliprole 0.4G, chlorantraniliprole 18.5SC, carbofuran 3G, cartap hydrochloride 4G and fipronil 5SC treated plants registered 36.67, 30.67, 25.33, 23.67, 22.00 and 16.33 nymphs per one pair of adult hoppers, respectively and significantly lower than control.

Deltamethrin 2.8EC registered a resurgence ratio of greater than one (1.73) resulting in flare up of BPH population. Other test insecticides recorded a resurgence ratio of less than one (<1). Based on the mean data of two seasons (*kharif*, 2020 and *rabi*, 2020-21), the highest reproductive rate of BPH was observed on deltamethrin 2.8EC (102.67 nymphs emerged per one pair of adult hoppers) which is superior to untreated control (62.50 nymphs). While, other insecticides registered lower fecundity (Resurgence ratio <1) indicating that they can be used judiciously for the management of insect pests in rice ecosystem.

Table 2. Effect of insecticides on the fecundity of BPH during *kharif* 2020 and *rabi,* 2020-21

T. No.	Treatment	Dose (ml l^{-1} or kg/ha)	Kharif 2020		Rabi, 2020-21		Mean	
			Reproductive rate (No. of nymphs hatched) @	Resurgence Ratio	Reproductive rate (No. of nymphs hatched) @	Resurgence Ratio	Reproductive rate (No. of nymphs hatched)@	Resurgence Ratio
T_1	Flubendiamide 20 WG	0.25 ml/l	56.67 (7.51) cd	0.83	36.67 (6.05) c	0.64	46.67 (6.82) c	0.75
T_2	Chlorantranilipro-le18.5 SC	0.3 ml/l	46.00 (6.75) de	0.68	25.33 (5.02) de	0.44	35.67 (5.96) de	0.57
T_3	Fipronil5 SC	2.0 ml/l	14.33 (3.75) f	0.21	16.33 (4.02) f	0.29	15.33 (3.89) f	0.25
T_4	Deltamethrin 2.8 EC	1.0 ml/l	107.00 (10.32) a	1.57	98.33 (9.90) a	1.73	102.67 (10.13) a	1.64
T_5	Carbofuran 3G	25.0 kg/ha	65.33 (8.07) bc	0.96	23.67 (4.85) de	0.42	44.50 (6.66) cd	0.71
T_6	Chlorantranilipro-le 0.4 G	10.0 kg/ha	38.33 (6.16) e	0.56	30.67 (5.53) cd	0.54	34.50 (5.86) e	0.55
T_7	Cartap hydrochlo-ride 4G	20.0 kg/ha	84.00 (9.14) b	1.24	22.00 (4.68) ef	0.39	53.00 (7.27) bc	0.85
T_8	Untreated control	Water spray	68.00 (8.25) bc		57.00 (7.54) b	-	62.50 (7.91) b	
F test			**Sig.**		**Sig.**		**Sig.**	
LSD (0.05)			**1.22**		**0.81**		**0.73**	
CV (%)			**9.38**		**7.78**		**6.11**	

*Mean of three replications; @ from eggs laid by 1 female in 7 days, figures in parentheses are square root transformed values. In a column, means followed by a common letter are not significantly different by LSD (P=0.05)

The present findings of higher fecundity rate of BPH on rice plants treated with deltamethrin is in conformity with the observations of several workers (Heinrichs *et al.*,1982; Zhu *et al*., 2004; Suri and Singh, 2011; Suri *et al.*,2015), who reported the reproductive stimulation as an important factor for causing resurgence in populations of BPH and WBPH. This increase in fecundity might be attributed to the stimulation of planthopper reproduction by the insecticide residues or their metabolites, chemical changes in the host plant receiving insecticides, or a combination of these two factors.

Conclusions

Based on the results from the present study, deltamethrin not only resulted in increased feeding rate but also enhanced the fecundity of BPH and consequently resulted in resurgence in the population of brown planthopper. Thus, the use of deltamethrin against insect pests in rice ecosystem may be avoided or not recommended. Other insecticides *i.e.*, flubendiamide 20WG, chlorantraniliprole (18.5SC and 0.4G), fipronil 5SC, carbofuran 3G and cartap hydrochloride 4G did not influence the reproductive rate of BPH (resurgence ratio <1). Hence, they can be used judiciously for the management of insect pests in rice ecosystem with periodical monitoring for the development of resistance and induction of resurgence.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Survey and symptomatology of false smut [*Ustilaginoidea virens* (Cooke) Takahashi] of rice

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Abstract

False smut of rice is one of the major emerging and destructive diseases especially in high yielding rice varieties of many rice growing regions of the India. False smut disease infection may initiate at the booting/flowering stage and visible symptoms appear at the grain filling stage. For tracking the disease status, we undertook a survey to assess the disease incidence and severity levels in the rice growing areas of South Gujarat. Rice growing areas *viz.*, Navsari, Surat, Valsad, Tapi and Dang and NAU farm were surveyed at grain maturity stage during the *kharif* 2017 and *kharif* 2018. In a random survey, two villages were selected in each district and per cent disease incidence, average smutted ball per panicle and disease severity index were recorded in each season. During field visits, we also recorded the symptoms of false smut on the basis of changing the colour of smut balls. Among the eleven surveyed locations, Jamalapada recorded maximum per cent disease incidence *i.e.*, 12.15, 10.06 and 11.11 during 2017, 2018 and mean of two years, respectively. The maximum average smutted ball per panicle recorded was 2.80 per cent in Jamalapada, during 2017 and 2.52 per cent in Khatal, during 2018, while the mean maximum average smutted ball was 2.63 per cent in Jamalapada. Maximum disease severity index, observed in Jamalapada was 34.02, and 24.65 and during 2017 and 2018, respectively with a mean of 29.15. Infected spikelets of the panicle transformed into yellowish-orange to olive-green colour smut ball, almost double the size of the normal rice grains and unfertilized florets infection led to the production of chaffy grains. In severe cases, complete chaffy panicles with numerous smut balls were observed.

Keywords: False smut, Rice, Symptomatology, Survey, *Ustilaginoidea virens*

Introduction

Rice false smut is also known as “pseudo-smut”, “green smut” and “Lakshmi (goddess of wealth and prosperity) disease” because the occurrence of this disease was recognized as a symbol of bumper harvest. False smut of rice caused by *Ustilaginoidea virens* (Cooke) Takahashi, was first reported from Tirunelveli in Tamil Nadu (Cooke, 1878). False smut disease has been observed in severe form since 2001 due to extensive cultivation of high fertilizer responsive cultivars and hybrids, excess application of nitrogenous fertilizer and an apparent change in climate. In recent years, it has emerged as the most devastating grain disease in majority of rice growing areas of the world (Singh *et al*., 2014). The disease occurs in more than 40 countries, especially in the rice producing countries of Asia and U. S. In India, the disease has been observed in severe form since 2001 in major rice-growing states, *viz.*, Haryana, Punjab, Uttar Pradesh, Uttaranchal, Tamil Nadu, Karnataka, Andhra Pradesh, Bihar, Jharkhand, Gujarat, Maharashtra, Jammu and Kashmir and Pondicherry (Dodan and Singh, 1996; Mandhare *et al*., 2008). In Gazipur, Bangladesh, 136 smut balls and 53.9 per cent infected grains were recorded per panicle (Nessa *et al*., 2016). In India, disease incidence of 10 to 20 and 5 to 85 per cent has been reported, respectively from Punjab and Tamil Nadu on different rice cultivars (Ladhalakshmi *et al*., 2012). False smut causes a reduction in seed germination up to 35 per cent. In damp weather, the disease can be severe and losses can reach more than 25 per cent. Recently in India, false smut has been found to cause heavy yield loss up to 75 per cent (Rashmi and Gokulapalan, 2014). The symptoms of the disease become discernible in the field at hard dough to the mature stage of the crop. The effects of the pathogen on the host are clearly seen only after flowering stage. In this stage pathogen grows in the ovary of an individual's kernel and transforms them into large, velvety greenish to black balls (pseudomorph) (Singh and Singh, 1987). Sometimes this pseudomorph is more than twice the diameter of the normal grains. In the initial stage, the balls are small and remain confined between the glumes and then they gradually enlarge and enclose the floral parts (Singh *et al*., 2008). Young spore balls are flattened, smooth, light yellow colour and covered by a membrane and later when the membrane bursts the colour changes to orange-yellowish, olive-green, green and finally the greenish-black. The pathogen also causes sterility of neighboring spikelets (Hashioka, 1971), ultimately leading to reduction in the grain weight (Dhindsa *et al.,* 1990). In general, only a few grains of a panicle are affected although sometimes several grains adjacent to smut balls may remain sterile resulting in chaffiness of the panicle (Rashmi *et al*., 2016). The false smut pathogen can infect rice florets at the booting/flowering stage where it destroys the ovary and leaves the style, stigma and anther buried intact in the spore mass. The typical symptom is the formation of a false smut ball that is attributable to the growth of a white fungal mass in a spikelet, protruding out from the gap between the palea and the lemma and eventually forming a ball-like colony, which produces numerous yellow or greenish-black chlamydospores sometimes covered by sclerotia (Guo *et al.*, 2012). Keeping in view, the continuous occurrence and widespread distribution of false smut disease, the extent of damage and economic losses caused by it, limited work has been done in this region on this disease. Hence, the present investigation was undertaken with the survey of false smut in rice growing areas of South Gujarat and study of the symptomatology of the disease.

Materials and Methods

Survey of rice false smut

Rice growing areas of South Gujarat were surveyed at grain maturity stage during the *kharif* 2017 and *kharif* 2018. A total of two surveys were conducted of five districts *viz.*, Navsari, Surat, Valsad, Tapi and Dang of South Gujarat and NAU farm. In a random survey for each district, two villages with two fields in each village were selected and in each field, four random sites (1m x 1m) were marked for observation. During each season, affected fields were surveyed for assessing the per cent disease incidence (PDI), average smutted ball (ASB) per panicle and disease severity index (DSI) of false smut disease of rice. Diseased plants showing false smut symptoms (pseudomorph) were collected in a paper bag from different rice growing areas of South Gujarat. The samples were subjected to further processing in the laboratory. The disease incidence parameters were worked out as per the following formula given by Singh and Dube (1978).

$$\text{Per cent disease incidence} = \frac{\text{Total number of infected tillers/m}^2}{\text{Total number of tillers/m}^2} \times 100$$

$$\text{Per cent infected grains} = \frac{\text{Total number of infected grains/panicles}}{\text{Total number of grain/panicles}} \times 100$$

Disease severity = Per cent infected tillers X Per cent infected grains

Symptomatology of false smut

During the field visits, colours of the smut balls *viz.*, (i) White, (ii) Orange, (iii) Olive green to greenish-black were also recorded.

Results and discussion

Survey of rice false smut in rice growing areas of South Gujarat

Field surveys were conducted during *kharif* 2017 and *kharif* 2018, at five districts *viz.*, Navsari (Partapor and Zari), Dang (Jamalapada and Khatal), Valsad (Balchondhi and Parvasa), Tapi (Panchol and Bhanwadi) and Surat (Haripura and Mahudi) and NAU farm (Navsari) for assessing the per cent disease incidence (PDI), average smutted ball (ASB) per panicle and disease severity index (DSI) of rice false smut disease. The results of the surveys revealed that disease incidence ranged from 1.49 to 11.11 per cent. The average smutted ball per panicle ranged from 1.07 to 2.63while the disease severity index varied between 1.97 and 29.15.

Per cent disease incidence of false smut of rice

Among eleven surveyed locations, the mean per cent disease incidence was 7.22 per cent in 2017. The maximum per cent disease incidence of 12.15 per cent in Jamalapada and minimum incidence of 1.71 per cent was recorded in Mahudi. In 2018, similar trend was observed. The mean disease incidence was 6.44 per cent with maximum incidence of 10.06 per cent in Jamalapada and minimum incidence of 1.27 per cent in Mahudi. The average per cent disease incidence across the two years was 6.83 per cent.

Average smutted ball per panicle of rice

The smutted balls per panicle were maximum in Jamalapada (2.80) and minimum average in Haripura (1.12) during 2017. The mean number of smutted balls per panicle was 1.88. In 2018, the mean smutted ball per panicle was 1.69 with maximum smutted balls per panicle of 2.52 observed in Khatal and minimum smutted ball per panicle recorded in in Haripura (1.18). However, the average smutted ball per panicle over the two years was found to be 1.79.

Disease severity index of false smut of rice

Among eleven surveyed locations, the mean average disease severity index was found 14.86 in 2017. The maximum disease severity index was 34.02 in Jamalapada whereas, minimum disease severity index was recorded 2.34 in Mahudi. In 2018, the mean average disease severity index was 11.85 with maximum disease severity index of 24.65 24.65 in Jamalpada and minimum disease severity index of 1.63 in Mahudi **(Table 1).** The average disease severity index across the years was 13.34 per cent.

Table 1: Surveys on the per cent disease incidence, average smutted ball and severity of false smut of rice during *kharif* 2017 and *kharif* 2018

District	Places	Per cent disease incidence (PDI)			Average smutted ball (ASB) / panicle			Disease severity index (DSI)		
		2017	2018	Mean	2017	2018	Mean	2017	2018	Mean
Navsari	Partapor	6.38	5.75	6.07	1.53	1.23	1.38	9.76	7.07	8.37
	Zari	7.36	6.84	7.10	1.60	1.40	1.50	11.78	9.58	10.65
Dang	Jamalapada	12.15	10.06	11.11	2.80	2.45	2.63	34.02	24.65	29.15
	Khatal	11.44	9.37	10.41	2.38	2.52	2.45	27.23	23.61	25.49
Valsad	Balchondhi	7.90	8.88	8.39	2.49	1.92	2.21	19.67	17.05	18.50
	Parvasa	8.11	6.68	7.40	2.10	2.26	2.18	17.03	15.10	16.12
Tapi	Panchol	7.28	6.12	6.70	1.61	1.57	1.59	11.72	9.61	10.65
	Bhanwadi	8.16	7.91	8.04	1.88	1.26	1.57	15.34	9.97	12.61
Surat	Haripura	2.39	1.99	2.19	1.12	1.01	1.07	2.68	2.01	2.33
	Mahudi	1.71	1.27	1.49	1.37	1.28	1.33	2.34	1.63	1.97
NAU Farm	Navsari	6.54	5.93	6.24	1.81	1.70	1.76	11.84	10.08	10.94

During the surveys, it was observed that the disease was found to be more severe in *viz.*, Jamalapada and Khatal of the Dang district. It may be due to favourable climatic conditions *i.e.*, high humidity, cloudy weather, low temperature and continuous cultivation of the hybrid and high yielding rice cultivars susceptible to false smut disease and recurrent appearance of the disease. The disease was found more severe in fields with the previous record of false smut over the years. Perusal of the literature revealed that false smut incidence was emerging as one of the major diseases of rice in Gujarat and its incidence vaied widely from one place to another place. Present results conform to the findings of Kapse *et al*., (2012) who recorded higher disease incidence in MTU-1010 variety (12.00%), with the incidence ranging from 0 to 12 per cent. Singh *et al*., (2012) reported highest disease incidence of 61.2 per cent in Pusa-1121 under late sown condition followed by late sown Sugandha-3 (58.40%) and timely sown Pusa-1121 (48.60%) while, least disease incidence was observed in timely sown Kranti variety (20.00%). Sanghera *et al*., (2012) reported that disease incidence ranged from 6.92 to 18.94 per cent in 2010 and 10.47 to 25.46 per cent in 2011 in different districts *viz*., Kulgam, Anantnag, Pulwama, Budgam of Kashmir. Higher disease incidence was recorded in Budgam followed by Kulgam. Ladhalakshmi *et al.*, (2012) found that the incidence of infected tillers ranged between 2 and 75 per cent in Haryana, 10 to 20 per cent in Punjab during 2009, and 5 to 85 per cent in Tamil Nadu during 2010. Rashmi and Gokulapalan (2014) recorded a maximum of 31.10 per cent infected tillers and 138.8 disease severity index in Upper Kuttanad of Kerala during 2011-2012 and the same trend was observed during 2012-13 with 42.00 per cent infected tillers and 123.9 disease severity index. Singh *et al.*, (2014) recorded 80 per cent disease incidence in Gaur Block of Basti district in Uttar Pradesh. Quintana *et al.*, (2016) recorded 40.0 per cent disease incidence in panicles and observed that the infected panicles had grains replaced by globose yellowish green masses of spores, with at least 2 to 3 smut balls per symptomatic panicles in IRGA-424 variety. Baite *et al.*, (2017) reported highest disease incidence, infected tillers, smutted balls and disease severity index of 55.61, 8.77, 6.47 per cent and 359.82, respectively in Pooja variety, in Cuttack (Odisha).

Symptomatology of the false smut disease of rice

The pathogen causing false smut disease of rice, *U. virens* initiated infection in the rice plants at the booting stage of the crop and visible symptoms appeared only after flowering at the grain filling stage of the rice crop. Due to the infection by the pathogen, the individual spikelets of the panicle were transformed in to yellowish-orange to olive-green colour ball-like structures called "smut ball or pseudomorph or pseudosclerotia" which were almost double the size of the normal rice grain **(Figure 1).** Infection in unfertilized florets resulted in most of the glumes remaining sterile without any visible sign of infection, and finally to production of chaffy grains.

Figure 1: Infected smutted balls and uninfected healthy seeds of rice: (i) Smutted balls (ii) Healthy seeds

The pathogen *U. virens* produced distinct symptoms after blooming when it infected the floret and transformed it into a large, velvety, yellow to orange pulverulent mass (pseudomorph) changing to olive-green to dark greenish in colour **[Figure 2: (A) and (B) i, ii and iii].** The smut balls, at the initial stage of infection by the fungus transformed individual grains of the panicle into a white dense mycelium which resembled the normal grain. After that it emerged out from the lemma and palea as whitish smut ball, covered by silvery white membrane **[Figure 3: (i) and (ii)].** During the later stages, the covering membrane ruptured exposing the yellow dust-like spores, technically the chlamydospores of the pathogen **[Figure 3: (iii) and (iv)]**. The yellowish smut ball transforming from yellowish-orange to olive-greenish in colour **[Figure 3: (v) and (vi)],** then to olive-green colour and later, from dark-green to greenish black colour and finally at maturity stage sclerotia detached from smut balls **[Figure 3: (vii) and (viii)].**

The pathogen was also found to cause chaffiness of the panicle and in severe cases, completely chaffy panicles with numerous smut balls were observed. Severely affected panicles appeared blackened by the time of harvest due to the presence of the black coloured chlamydospores of the pathogen.

Hu *et al*., (2013) also observed that the smut balls were first covered by a silvery-white membrane that ruptured and changed colour from yellow-orange to olive-green and then greenish black at maturity. Rashmi *et al*., (2016) observed that false smut was found to infect the rice plants at the flowering stage of the crop. Due to the infection by the pathogen, the individual spikelets of the panicle were found to get transformed into yellow to orange coloured smut balls which were almost double the size of the normal rice grains. Kannahi *et al*., (2016) reported that the false smut symptoms appeared on the spikelet at maturity. Sanghera *et al*., (2012), Kumar *et al.*, (2014), Singh *et al*., (2014) and Lin *et al*., (2018) found that, the false smut of infected grain balls (smutted ball) initially become a yellowish or orange in colour and changed to green or olive-green colour.

Figure 2: Symptoms of false smut disease of rice in field

(A) False smut balls in the field

(B) Change of colour of smut ball (i) White (ii) Orange (iii) Olive green

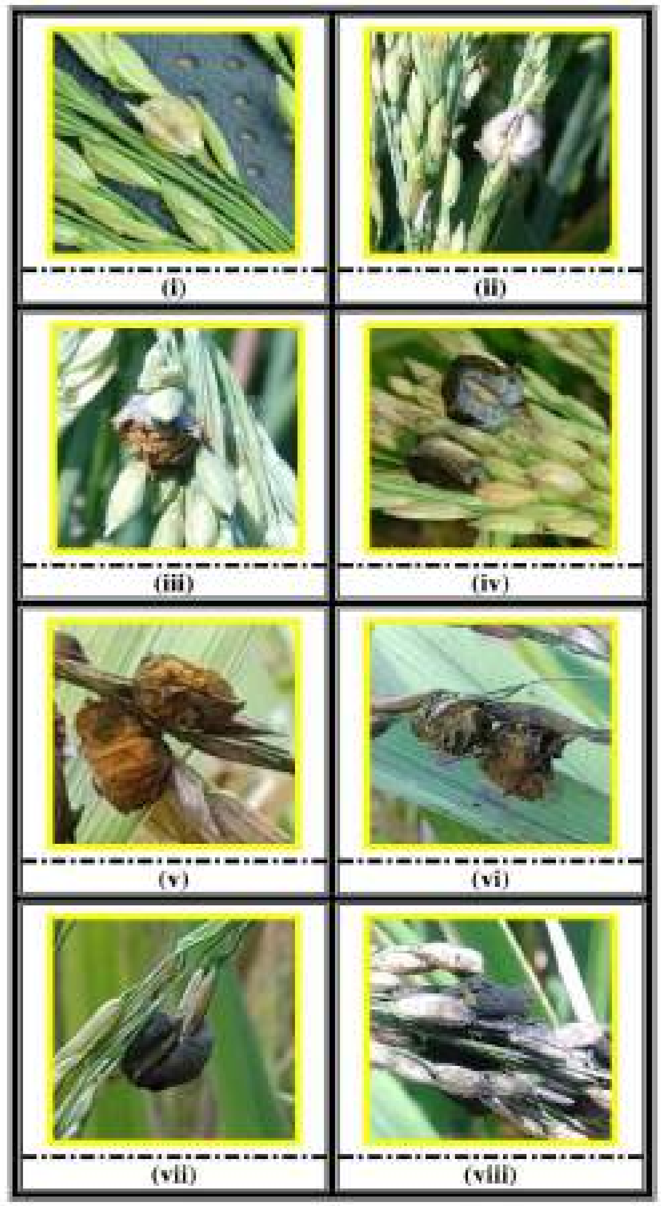

Figure 3: Developmental stages of false smut balls in infected rice panicles

(i) Development of mycelium inside the grain **(ii)** Emerging of mycelium with silvery white membrane and developing of light yellow chlamydospores inside the membrane **(iii) & (iv)** Bursting of silvery white membrane and spread of chlamydospores **(v)** Colour changing from yellow to orange smut ball **(vi)** Transformation of orange smut ball into olive-greenish **(vii)** Developed olive-greenish to black smut ball **(viii)** Sclerotia detaching from smut balls

Conclusions

The information showed that due to infection of *U. virens,* spikelets of the panicle were transformed into yellowish-orange to olive-green colour ball-like structures called "smut balls". *U. virens* attacked almost all the rice growing areas of South Gujarat and maximum in Dang district because of favorable climatic conditions like high humidity, cloudy weather, low temperature and continuous cultivation of the hybrid and high yielding rice cultivars susceptible to false smut disease. It was evident from survey data that false smut is evolving as one of the major threats to the rice-producing areas of Gujarat.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Evaluation of essential oils against rice sheath blight disease in kuttanad wetland ecosystem

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Abstract

Field experiments were conducted at Rice Research Station, Kerala Agricultural University, Moncompu during *Rabi 2018-19, Kharif2019* and *Kharif 2020* under AICRIP programme for rice sheath blight control through organic essential oils. The tested essential oils were citronella oil, eucalyptus oil, cedar wood oil, nirgundi oil, lemon grass oil, clove oil, neem essential oil, emulsifier with standard check fungicide carbendazim 50 WP. The pooled analysis of three seasons showed that neem essential oil @ 2 ml/l was superior in reducing the sheath blight disease incidence (19.28 %) on par with standard check fungicide carbendazim 50 WP (21.64 %) and lemon grass oil @ 2 ml/l (23.11 %). The data on severity proved that the neem essential oil treatment resulted in less severity of sheath blight (16.32%) compared to lemon grass oil (17.85 %) and standard check fungicide carbendazim (18.91%). The neem essential oil treatment also yielded the highest (6532 kg/ha) followed by standard check fungicide carbendazim (5878 Kg/ha) and lemon grass oil (5762 kg/ha).

Keywords: Rice, sheath blight, essential oil, fungicide, severity

Introduction

Rice (*Oryzae sativa* L.) is the primary staple food in many countries. In India, it is cultivated in an area of 44 M ha with 105 M T of production and 2386 kg ha^{-1} of productivity. Sheath blight is a fungal disease of rice caused by a necrotrophic soil-borne fungus *Rhizoctonia solani*–AGA1-IA. It survives either as sclerotia or mycelia in the debris of host plants. The sclerotia float to the surface of flooding water in the rice fields and germinate on rice sheaths forming infection cushions or appressoria during the infection process (Richa *et al.*, 2016). *R. solani* can attack rice plants at any growth stage (Dath, 1990) but disease incidence and severity increase with increase in plant age (Singh *et al.*, 2004) and the resistance and susceptibility in rice genotypes are better differentiated on mature plants than on seedlings (Dath, 1990).

The weather and soil conditions such as high relative humidity, temperature and extremely acidic soil pH prevailing during *Kharif* and *Rabi* in Kuttanad are conducive for the occurrence of sheath blight disease. Sheath blight is a worldwide destructive disease causing significant yield loss and quality degradation (Savary *et al*., 2006). Sheath blight of rice is important location specific disease in Kuttanad region of Kerala causing 30-37 per cent yield loss (Surendran *et al*., 2019). This region is a hot spot for rice diseases and chemical fungicides are commonly used to control diseases. Periodic prophylactic spraying at booting stage to ward off disease incidence has become a regular practice of Kuttanad farmers. However, this practice has often resulted in spontaneous disease outbreaks. The indiscriminate use of fungicides to control sheath blight disease has led to acute environmental pollution in this region. Laterally it leads to health hazards to human beings and all other living organisms. Hence, eco-friendly fungicidal formulations have become the need of the hour to reduce this environmental pollution. Essential oils or crude plant extracts can be used as pesticide (Strangarlin *et al.,* 1999) and induce fruit resistance through proper elicitor compounds (Schwan-Estrada *et al.*, 2005).

Currently, biofungicides based on natural product are effective against plant diseases. The agricultural use of natural products is an advisable and desirable alternative to the application of synthetic chemicals. Application of natural essential oils from lemon grass (*Cymbopogon citratus*) against anthracnose (*Colletotrichum gloeosporioides*) has been increasingly compromised by the development of pathogen resistance (Duamkhanmanee, 2008). Studies on evaluation of essential oils against sheath blight disease was proposed as a new disease management approach under AICRIP programme during the year 2018 and it was conducted at Rice Research Station, Moncompu. Considering the yield loss due to this disease and keeping in view the effect of chemical pesticides resulting in environmental pollution, the present study involving field experiments were carried out to evaluate different essential oils available in the market, for their efficacy against sheath blight of rice.

Materials and Methods

Field experiments were conducted at Rice Research Station, Moncompu, Alappuzha during *Rabi 2018-19*, *Kharif 2019* and *Kharif 2020* under AICRIP programme for sheath blight control. The treatments included essential oils such as citronella oil, eucalyptus oil, cedar wood oil, nirgundi oil, lemon grass oil, clove oil and neem essential oil as well as emulsifier and standard check fungicide carbendazim 50 WP. The experiments were laid out in randomised block design with 3 replications in 5×2m plots using the susceptible variety Uma (MO 16). The N, P, K fertilisers were applied as per Package of Practices recommendations. The treatments were applied as foliar spray after the appearance of sheath blight symptoms under natural conditions. Three sampling units of 1 m^2 area were fixed in each plot at random and observations were recorded on disease incidence and severity before the spray and 15-20 days after the spray. Percentage of disease incidence was calculated based on the number of infected tillers on 25 plants per sampling unit. Degree of severity was graded based on height of the plant portions affected by the disease and expressed as percentage of the total area as per the SES scale of rice (IRRI, 2014). Grain yield of each plot was recorded and expressed in kg/plot at 14% moisture. Data on percentages were transformed to arcsine values and analysis of variance was performed with transformed values. Significance among mean treatments was determined according to Duncan's multiple range test (Gomez and Gomez, 1984).

Results and Discussion

During *Rabi 2018-19*, observations on sheath blight incidence showed that the eucalyptus oil was the most effective in reducing sheath blight incidence (14.42 %) followed by cedar wood oil (15.56 %), standard check fungicide carbendazim (16.11 %) and neem essential oil (19.73 %). Disease severity was also less in neem essential oil (18.05 %), lemon grass oil (18.81 %), eucalyptus oil (19.55 %) treatments and was on par with standard check fungicide carbendazim (20.44 %), compared to other treatments. The grain yield data showed that the neem essential oil recorded highest yield of 8996 kg/ha followed by emulsifier (8837 kg/ha) and standard check fungicide carbendazim (8400 kg/ha).

During *Kharif* 2019, the essential oils *viz*., neem essential oil (19.73% & 15.56%), lemon grass oil (20.62% & 16.32%), eucalyptus oil (24.73% & 22.30%) and systemic fungicide carbendazim (22.87% & 18.72%) were found equally effective in controlling the sheath blight incidence and severity, respectively. The recorded yield was comparatively low and neem essential oil treated plot showed higher yield of 3400 kg/ha compared to other treatments.

During *Kharif 2020*, the data showed that the neem essential oil was found superior in decreasing the sheath blight disease incidence (18.43 %) and severity (15.34%) followed by lemon grass oil (24.88% and 18.24%), carbendazim (25.70% and 17.36%) and Citronella oil (25.99% and 18.53%). The maximum yield of 8367 kg/ha was obtained with lemon grass oil followed by neem essential oil (7200 kg/ha) and standard check fungicide carbendazim (6333 kg/ha). The control plot recorded the lowest yield of 5133 kg/

ha. The pooled data of three seasons **(Table 1)** revealed that, neem essential oil (T_7) treatment resulted in maximum reduction in disease incidence (10.99%) followed by carbendazim (13.65%), eucalyptus oil (15.12%), lemon grass oil (15.49%) and emulsifier (21.11%).

Sheath blight severity was also the least in neem essential oil treatment (7.99) compared to lemon grass oil (9.43), standard check fungicide carbendazim (10.51), citronella oil (11.28) and emulsifier (12.08) **(Table 2).**

Yield data **(Table 3 and Fig.1)** revealed that the highest yield (6532 kg/ha) was recorded in the treatment T_7 (neem essential oil) followed by standard check fungicide carbendazim (5878 kg/ha), lemon grass oil (5762 kg/ha) and emulsifier (5757 kg/ha).

Even though the lemon grass oil showed highest yield during *Kharif 2020*, the pooled data of three seasons revealed that the neem essential oil was significantly superior to all other treatments including standard check fungicide. Bowers and Lock (2004), reported that the cinnamon oil and clove oil effectively reduced the incidence of both pre-emergence rotting and post emergence wilting of peanut seedlings in *A. niger* infested soil.

In the current study, neem essential oil showed maximum reduction in sheath blight incidence and severity when compared to lemon grass oil, emulsifier and citronella oil.

Souza Junior *et al.*, (2009) found that essential oils from "alecrim-pimenta" (*Lippia sidoides Cham.*), wild basil (*Ocimum gratissimum L.*), lemon grass (*Cymbopogon citratus Stapf*) and "cidrao" (*Lippia citriodora Kunth*) inhibited the germination and mycelial growth of *Colletotrichum gloeosporioides* conidia. Rozwalka *et al.*, (2008) proved that the partial or total inhibition of *Glomerella cingulata* and *C. gloeosporoioides* mycelial growth *in vitro* showed that most of the studied essential oils and medicinal plants present biologically active compounds with antifungal effect.

In the present study, the pooled data analysis of three seasons showed that neem essential oil, lemon grass oil and emulsifier were highly effective and on par with

Table 1. Influence of different essential oils on sheath blight disease incidence (%) during *Rabi 2018-19*, *Kharif2019* and *Kharif 2020* (pooled data of three seasons)

S. No	Fungicides	Dose/L	Sheath blight Incidence (%)			
			Rabi 2018-19	*Kharif2019*	*Kharif 2020*	Mean
1	Citronella oil	2.0 ml/l	15.92 (23.50)	37.03 (37.46)	19.25 (25.99)	24.06(29.33)
2	Eucalyptus oil	2.0 ml/l	6.29 (14.42)	17.59 (24.73)	21.48 (27.56)	15.12(22.87)
3	Cedar wood oil	2.0 ml/l	7.22 (15.56)	32.03 (34.45)	33.70(35.49)	24.32 (29.53)
4	Nirgundi oil	2.0 ml/l	7.96 (16.32)	40.55(39.52)	31.85(34.33)	26.79(31.11)
5	Lemon grass oil	2.0 ml/l	16.29(23.73)	12.40(20.62)	17.77(24.88)	15.49(23.11)
6	Clove oil	2.0 ml/l	12.77(20.88)	33.70(35.49)	30.37(33.40)	25.75(30.46)
7	Neem essential oil	2.0 ml/l	11.48(19.73)	11.48(19.73)	10.00(18.43)	10.99(19.28)
8	Emulsifier	2.0 ml/l	13.88(21.81)	29.07(32.58)	20.37(26.78)	21.11(27.35)
9	Carbendazim	0.6 g/l	7.78(16.11)	15.18(22.87)	18.88(25.70)	13.65(21.64)
10	Control	--	52.96(46.66)	72.96(58.63)	67.40(55.18)	64.44(53.37)
	LSD @5% (*P*= 0.05)		**0.216**	**6.177**	**8.673**	
	CV (%)		**9.883**	**10.470**	**15.361**	

*Figures given in parentheses are arcsine transformed values

Table 2. Influence of different essential oils on sheath blight disease severity (%) during *Rabi 2018-19*, *Kharif2019* and *Kharif 2020* (pooled data of three seasons)

S. No	Fungicides	Dose/L	Sheath blight severity (%)			
			Rabi 2018-19	*Kharif 2019*	*Kharif 2020*	Mean
1	Citronella oil	2.0 ml/l	12.53(20.70)	10.40(18.81)	10.91(18.53)	11.28(19.55)
2	Eucalyptus oil	2.0 ml/l	11.23(19.55)	13.21(21.30)	12.13(20.36)	12.19(20.36)
3	Cedar wood oil	2.0 ml/l	13.33(21.39)	12.10 (20.36)	13.19 (21.22)	12.87(20.96)
4	Nirgundi oil	2.0 ml/l	13.58(21.56)	12.03(20.27)	13.27(21.30)	12.96(21.05)
5	Lemon grass oil	2.0 ml/l	10.46(18.81)	7.96(16.32)	9.89(18.24)	9.43(17.85)
6	Clove oil	2.0 ml/l	12.46(20.62)	11.63 (19.91)	12.67 (20.79)	12.25(20.44)
7	Neem essential oil	2.0 ml/l	9.60(18.05)	7.28 (15.56)	7.09(15.34)	7.99(16.32)
8	Emulsifier	2.0 ml/l	13.40(21.47)	10.79 (19.09)	12.05(20.27)	12.08(20.27)
9	Carbendazim	0.6 g/l	12.21(20.44)	10.37(18.72)	8.95(17.36)	10.51(18.91)
10	Control	--	19.58(26.21)	21.23(27.42)	15.62(23.26)	18.81(25.70)
	LSD @5% (*P*= 0.05)		**1.808**	**NS**	**1.559**	
	CV (%)		**3.884**	**11.989**	**3.451**	

*Figures given in parentheses are arcsine transformed values

Table 3. Influence of different essential oils on grain yield (kg/ha) during *Rabi 2018-19*, *Kharif2019* and *Kharif 2020* (pooled data of three seasons)

S. No	Fungicides	Dose/ l	Grain yield (kg/ha)			
			Rabi 2018-19	*Kharif2019*	*Kharif 2020*	Mean
1	Citronella oil	2.0 ml/l	6908	3367	5800	5358
2	Eucalyptus oil	2.0 ml/l	7461	2833	5133	5142
3	Cedar wood oil	2.0 ml/l	6779	3067	5200	5015
4	Nirgundi oil	2.0 ml/l	7531	3233	5667	5477
5	Lemon grass oil	2.0 ml/l	5552	3367	8367	5762
6	Clove oil	2.0 ml/l	7404	2700	6033	5379
7	Neem essential oil	2.0 ml/l	8996	3400	7200	6532
8	Emulsifier	2.0 ml/l	8837	2867	5567	5757
9	Carbendazim	0.6 g/l	8400	2900	6333	5878
10	Control	--	3065	2200	5133	3466
	LSD @5% (*P*= 0.05)		**1713.811**	**610.447**	**942.029**	
	CV (%)		**14.204**	**11.888**	**9.318**	

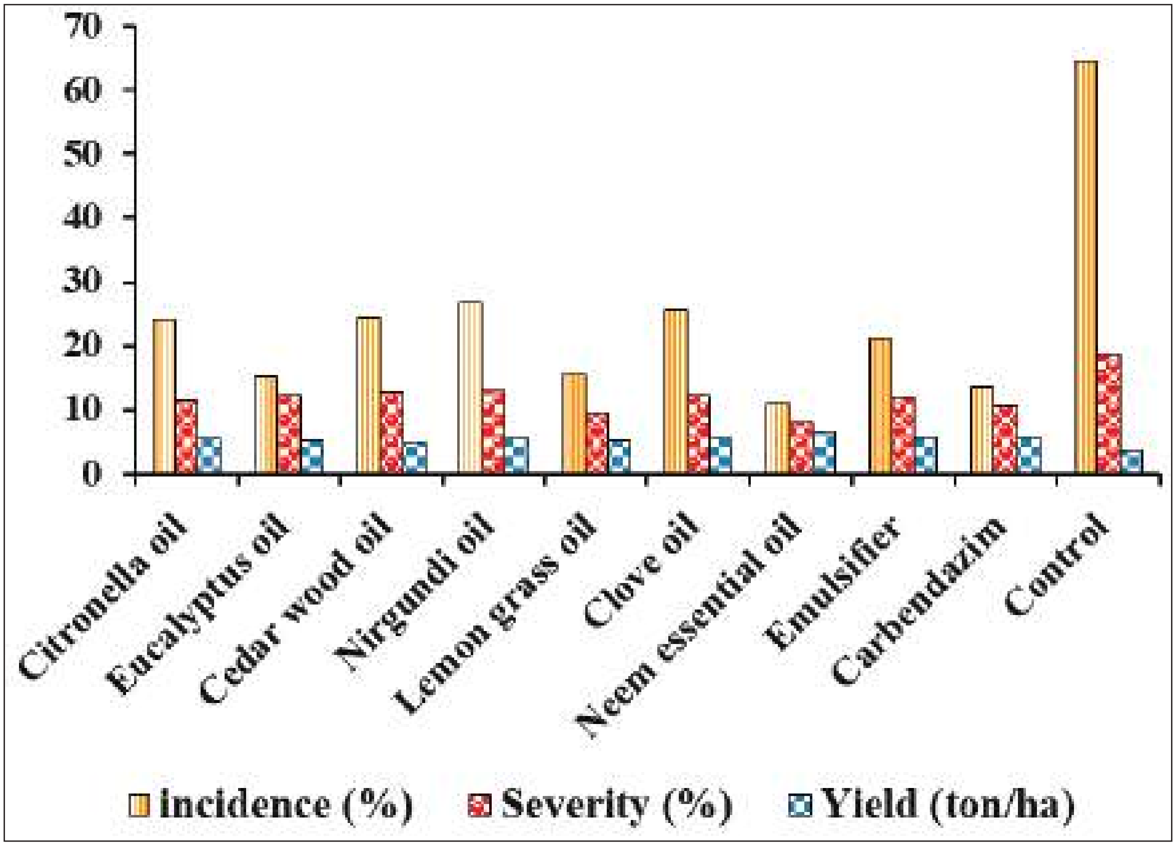

Figure 1. Effectiveness of different essential oils on sheath blight disease incidence, severity (%) and grain yield (ton/ha)

standard check fungicide carbendazim. The essential oils were very effective and could significantly reduce the sheath blight disease incidence and severity compared to the chemical fungicide. Essential oils are made up of many different volatile compounds which showed the anti-fungal and anti-microbial effects due to the result of many compounds acting synergistically (Jobling, 2000).

The present results also conform to the earlier findings that the selected essential oils *viz*., neem essential oil, lemon grass oil and emulsifier with different mechanisms of disease control will have an additive phototonic effect and result in higher yield.

Overall, it was evident from the present study that the neem essential oil, lemon grass oil and emulsifier @ 2.0 ml/l can be recommended for the effective control of rice sheath blight disease and thereby reduce the use of toxic chemical fungicides in the Kuttanad ecosystem.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Agricultural trade and environment nexus- A case study of rice exports from India

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Abstract

In recent years there is discussion regarding nexus between agricultural trade and environment and shared responsibility in addressing trade related environmental externalities. In the current study, this nexus is examined focusing on rice exports from India in the recent decade. India's share in quantity of world rice exports was 22.45 per cent on an average in the decade 2010-2019. However, in the same period India's share in water footprint of world rice exports was 28.29 per cent. Further average economic productivity of water in rice exports was 0.24 and 0.22 USD/ M^3 in the case of World and India, respectively. The estimated methane emission associated with Indian rice exports ranged between 2.42 to 11.31 per cent of total methane emission from rice production. Totally, 47 countries were involved as top 5 destinations of different types of rice exports from India. Land scarcity, water scarcity, water availability for agriculture, agricultural trade policies in these countries were the underlying factors of the observed rice export pattern of India. Out of these 47 trade partners, in 27 countries, methane emission intensity in paddy was higher than that of India in 2017, but paddy area was lower compared to India. Several national level and international level policy options are available for handling the environmental externalities associated with rice exports from India.

Keywords: Paddy, Rice, Trade, Environment, Externality, Agricultural trade, Carbon, Water, Methane, GHG, Emission

Introduction

Agricultural trade plays an important role in achieving the global food/nutritional security and rural livelihood security. Trade can also serve as a climate change adaptation mechanism in agriculture (Konar *et al., 2016*; Gouel and Laborde, 2021). But Agricultural trade can also affect environment as resource use intensity in production and processing of crops and animal products varies across regions and over time and in turn may contribute to climate change. Hence in recent years, studies focusing on nexus between Agricultural trade and Environment have been carried out quantifying virtual land trade, virtual water trade and trade led Green House Gases (GHG) emissions.

In agriculture, different activities like crop production, livestock production and land use change are the major sources of GHG emissions. Trade in agricultural commodities is leading to specialization in production of some commodities in some countries based on resource availability, technology availability and also sometimes due to trade policy. Thus some countries are producing some agricultural commodities not only for meeting domestic demand but also for meeting export demand. Rice is one such commodity. Davis *et al.,* (2019) reported disproportionately large contribution of rice production to resource use, greenhouse gases, and climate sensitivity relative to its share of *Kharif* cereal calorie production in India. Rice crop is "both a cause and victim of climate change" with significant sustainability implications for India (Prasanna, 2018; Rupal, 2019) as well as at global level (Sporchia *et al.,* 2021). In this backdrop the current study attempts to analyse the dynamics of rice exports from India in the last decade (2010-2019), quantifying rice trade led environmental externalities, understanding underlying factors and identifying some options for addressing these externalities.

Projections regarding rice production and trade

India is an important rice exporting country contributing 28 per cent of total global rice exports in 2019. OECD-FAO (2020) projected that global rice production will reach 582 million tons in 2029, Asia accounting for an increase of 61 million tons, with highest growth in India. India's share in world rice export is projected as 30 per cent in 2029. OECD-FAO (2020) projected that India will export 14 per cent of its total rice production by 2029. In the calendar year 2021, global rice trade is forecasted as 45.6 million tons against India's rice export forecast of 14 million tons and the global rice trade in the year 2022 as 46.4 million tons (USDA, 2021).

At global level it is projected that rice area will more or less be at 152.45 million ha in 2050 compared to 152.73 million ha in 2010. But a moderate decline in area will be likely in Asia (135.31 to131.51 million ha) and Latin American Countries (6.42 to 5.79 million ha) (Kruseman *et al.*, 2020). The climate change could decrease global rice production by approximately 5%. The decrease in supply would be associated with about an 18-24% higher price (Reardon *et al.*, 2015) indicating a greater challenge in securing rice production than is currently felt. Population growth around 2050 is likely to result in doubling of population in Africa and an increase of 25% in south Asia (United Nations, 2014). In south Asia, urbanization may increase in 2050, but in Africa the opposite may be true with rural areas becoming more densely populated (Swerts *et al.*, 2014, Racki *et al.*, 2014). More than 90% of the global 500 million MT of rice is produced and consumed in Asia (FAO) which is produced from 30% of the total arable land of this region. However, the highest percentage increase in demand for rice is projected for Africa, where rice is becoming a luxury good.

Gouel and Laborde (2021) projected that by the year 2080, with climate change, import volume of rice will increase by 38 % compared to baseline value pertaining to the year 2011. As the traditional rice exporters are tropical countries that will be severely hit by climate change, new exporters emerge *viz*., China, Korea and Japan. Thus the pattern of international trade flows in rice may look extremely different from now because of the effects of climate change (Gouel and Laborde, 2021). According to Sporchia *et al.*, (2021) in view of many constraints to rice production in Africa, African import of rice is expected to gain importance in the next years. African Countries are expected to be the destination of 44% of global rice exports by 2027 compared with 36% in 2016 (FAO, 2019).

Nexus between agricultural (rice) trade and virtual water trade

Kampman (2007) reported that during 1997-2001, 35 per cent of virtual water flow in interstate trade in India was associated with milled rice trade. They observed largest interregional net virtual water flow from North India to East India and it is in just opposite direction of proposal under interlinking of river projects. According to Ghosh and Bandyopadhyay (2009) by resorting to import of paddy instead of cultivation in Tamil Nadu and Karnataka, both states can increase their water saving.

At global level, Hoekstra and Hung (2005) estimated that**,** during the period 1995-99, virtual water export was 13 per cent of water used for crop production. They observed that U.S, Canada, Thailand, Argentina and India were net virtual water exporters. At global level, approximately eleven per cent of non-renewable groundwater use for irrigation was embedded in international food trade of which two thirds was exported by Pakistan, the USA and India (Carole *et al.*, 2017). Global Ground-Water Depletion (GWD) has increased by 22 per cent in ten years from 240 Km^3 in 2000 to 292 Km^3 in 2010 (Carole *et al.*, 2017). In case of India, GWD increased from 1.5 Km^3 in 2000 to 3 Km^3 in 2010. India kept most of its large GWD based crop production for domestic use (only 4% of GWD exported). Individual crops contributing most to global GWD transfers were rice (29%) followed by wheat. Even though most of India's GWD is for domestic consumption, India is still the third-largest GWD exporter primarily via rice and cotton mainly to China (Carole *et al.*, 2017). Rosa *et al.*, (2019) observed that about 52 per cent of global irrigation was unsustainable, 15% of it was virtually exported, with an average 18% increase (75 to 88 Km^3) between year 2000-2015. India consistently acted as net exporters of Unsustainable Irrigation Water Consumption (UWC) based crops. They reported that India kept 90% of UWC for domestic consumption. India exported unsustainably produced cotton and rice to China and Bangladesh (Rosa *et al.,* 2019).

Yang *et al.,* (2006) observed that during 1997-2001 in the case of rice, volume of virtual water export was more than virtual water import at global level. This indicated that rice production in exporting countries required more water than the production in importing countries. Some studies observed India as net water exporter in agricultural trade in general (Chapagain *et al.,* 2006) and in the case of rice trade in particular (Sree Vidhya and Elango, 2019). Chouchane *et al.,* (2018) projected that global international trade in staple crops will increase by a factor of 1.4-1.8 towards 2050 (compared to the average in 2001-2010) in order to meet the staple food needs of the 42 most water-scarce countries in the world as a result of population growth. They observed continuous increase in net import of staple crops per capita with decreasing water availability per capita (1961-70 to 2001-10). However, India, Pakistan and Sri Lanka were the exceptions to the general pattern with decreasing net staple food imports. India and Pakistan shifted to become net exporters despite their increasing water scarcity and are expected to become net importers of staple crops by 2050 (Chouchane *et al.,* 2018).

Nexus between (Cereal) Trade and GHG transfer

Shapiro (2016) has estimated that the opening of border raises global CO_2 emission in the order of 5% compared to a self sufficient situation without any international trade. On the other hand, Nguyen (2020) using the panel data of 89 economies from 1995-2012, examined major drivers of agricultural emission. They observed that trade openness and Foreign Direct Investment (FDI) inflows have significantly negative effects on GHG emission from agriculture in the long run.

Sporchia *et al.,* (2021) used Physical Trade Analysis (PTA) based on Material Flow Analysis (MFA) to analyse three most relevant environmental stressors associated with global rice production *viz.,* water, land-use and methane emission in 167 countries during the period 2000-2016 (17 years). Total water use grew by 8% (from 892 to 962 Gm^3) and land use and methane emission increased by 7% (154 to 165 Mha and from 23 to 25 M tons, respectively). Green and blue water use increased by 9% and 2% passing from 689 to 753 Gm^3 and from 204 to 209 Gm^3, respectively. Share of rice trade in the selected stressors was 6%. Despite the general growth, large amount of land, water and methane emission were saved due to improvement in rice production efficiency. Intensity of global rice production resulted in saving of 240 Gm^3 water, 40 m ha of land and 31 K tons of methane. But the saving was not sufficient to reduce the increase. The savings were concentrated in some areas (South East Asia, Southern America). India saved 77 Gm^3 of water (of which 58 green and 19 blue), 14 M ha of land and 6 Tg of methane). The share of virtual water, land and emission grew from 3.8 to 6.2% for total water, 3.5 to 5.7% for land and from 4.4% to 5.7% methane emission from 2000 to 2016. Substantial part of the Asiatic production of rice was driven by African demand (Benin, Cote D'Ivoire, Kenya, Senegal, Cameroon and Mozambique). Benin, the second largest importer of rice after China, was among the largest virtual water, land and emission importer. In 2016, Asia was the largest import region for virtual water, land and emission (43,44 and 40%) followed by Africa, Europe and North America. If yield of rice at global level improved by 0.5 tons/ha, it would result in a global reduction of about 10% of rice related environmental toll for the same amount of rice production.

Methodology

Most of the past studies on trade and environment nexus in the context of India were with limited focus *i.e.,* they estimated aggregate virtual water (resource) trade and water (resource) saving associated with different commodities trade. In the current study besides estimation of virtual water trade, economic water productivity and efficiency in virtual water trade associated with rice trade are analysed. While analysing these issues, current study focused on different types of rice exported from India *viz*., Rice in the husk (Paddy), Husked brown rice, Semi-milled/wholly milled rice and Broken Rice contrary to past studies which focussed on total (aggregate) rice exports. These are referred as paddy, brown rice, milled rice and broken rice, respectively in subsequent sections of this paper. GHG emission associated with rice trade also estimated following IPCC (2006) method. Finally, the underlying rationale behind rice exports and options (technologies, policies) for addressing sustainability issues associated with Indian rice trade are discussed.

Data on rice exports for the years 2009-10 to 2019-20 was collected from APEDA (Agricultural and Processed Foods Export Development Authority) website. Data on different types of rice exports was collected from COMTRADE website. Water Foot print estimates of Mekonnen and Hoekstra (2010) were used in Economic water productivity computations. Data on Renewable Water Resource Available Per capita (RWRAP) and share of Agricultural Water Withdrawal in Total Water Withdrawal (AWWTWW) of different countries in the year 2017, was collected from FAOSTAT database. Data on arable land available per capita, rice area harvested, and Emission Intensity of rice cultivation in different countries was collected from FAOSTAT database. Simple descriptive statistics have been used in analysing the data.

Results and Discussion

Rice exports from India increased from 2.16 million tons in 2009-10 to 9.49 million tons in 2019-20 (**Figure 1**). The share of rice exports in total rice production in India ranged between 2.42 per cent to 11.31 per cent in different years of the last decade (**Figure 2**). Average quantity of rice exports from India from 2009-10 to 2019-20 stood at 9.10 million tons accounting for 8.56 per cent of average rice production. In 2019 Global trade in rice fell due to reduced Asian import demand in particular from Bangladesh, China and Indonesia (OECD-FAO, 2020). Accordingly, rice exports from India also declined to 9.49 million tons in 2019-20, compared to 11.95 million tons in 2018-19, further the decline was confined to non-basmati rice. In the following section, rice exports and water productivity details are discussed focusing on (i) four types of rice exports from India during the calendar years 2010-2019 and (ii) basmati and non-basmati rice exports during 2009-10 to 2019-20.

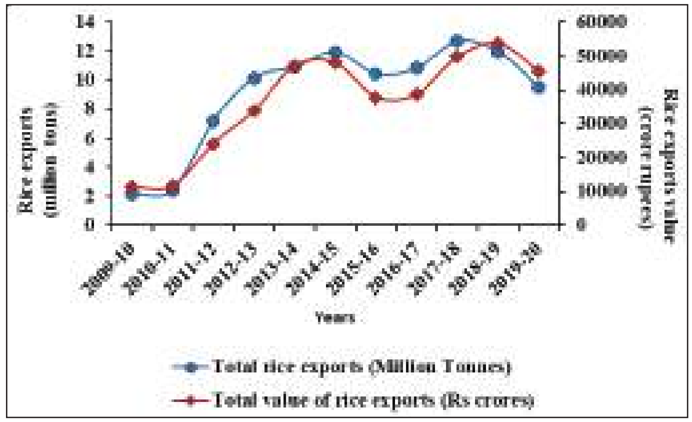

Figure 1. India's rice exports quantity and value

Basmati rice accounted for almost 6% of the total rice produced in India (Kumar, 2019). The share of basmati rice in total quantity of rice exported from India declined from 93.53 per cent in 2009-10 to 46.94 per cent in 2019-20 (**Figure 2**). This is consequence of policy of removal of ban on non-basmati rice exports during later part of the year 2011. However, in absolute terms, quantity of basmati rice exports from India doubled in 2019-20 compared to 2009-10. In all the years under consideration, unit value realized from basmati rice exports ranged between 2.06 to

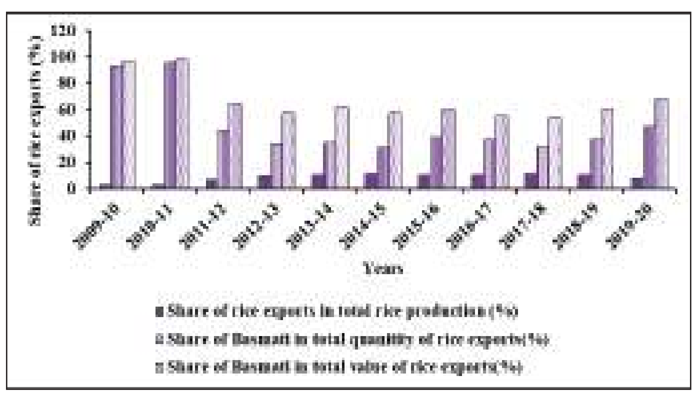

Figure 2. Share of rice exports

3.13 times of unit price realized from non-basmati rice exports (**Table.1**). Further ratio of non-basmati rice export price to domestic MSP ranged from 1.04 to 1.65 with lowest value in 2019-20. But Kumar (2019) reported lower export price of rice compared to wholesale price and squeeze in margin of farmers.

Table 1. Ratio of rice export price to MSP in India

Year	Ratio of unit value of exports of Basmati and non-basmati rice	Ratio of Basmati export price to MSP of rice	Ratio of Non-basmati export price to MSP of rice
2009-10	2.06	3.39	1.65
2010-11	2.12	3.22	1.52
2011-12	2.25	2.98	1.33
2012-13	2.60	2.96	1.14
2013-14	3.13	3.93	1.25
2014-15	3.02	3.62	1.20
2015-16	2.37	2.63	1.11
2016-17	2.15	2.43	1.13
2017-18	2.49	2.82	1.13
2018-19	2.68	2.80	1.05
2019-20	2.44	2.53	1.04

MSP = Minimum support price

India's share in quantity of world exports of paddy ranged between 0.62 to 9.70 per cent across different years in the decade 2010-2019 (**Table 2**). India's share in world rice exports quantity ranged between 9.10 to 31.22 per cent in case of milled rice, 0.01 to 5.13 per cent in the case of brown rice and 0.01 to 27.88 per cent in the case of broken rice. On average, the share of India in quantity of world rice exports was 6.64, 1.01, 25.97 and 17.88 per cent in paddy, brown rice, milled rice and broken rice, respectively. On the other hand, average share of India in value of World rice exports was 6.86, 0.82, 29.58, and 14.26 per cent in paddy, brown rice, milled rice and broken rice, respectively. Thus India's share in average world exports of the four rice forms (put together) was 22.45 and 25.84 per cent in quantity and value, respectively (**Table 2**). The unit value realized from world rice exports was more than unit value realized in rice exports from India in 2, 6, and 9 years in the case of rice in husk (paddy), brown rice, and broken rice, respectively (**Figure 3**). This indicates fluctuating competitiveness of India's' rice exports across four types of rice products. In all the ten calendar years (2010 to 2019), milled rice share in total Indian rice export quantity (ranging between 86 to 99 per cent) and value (ranging between 93 to 99 per cent) was the highest (**Table 3**). It was followed by broken rice and rice in the husk *i.e.*, paddy (except in year 2010). Further only in the case of milled rice, share of value of exports was more than share of quantity of exports.

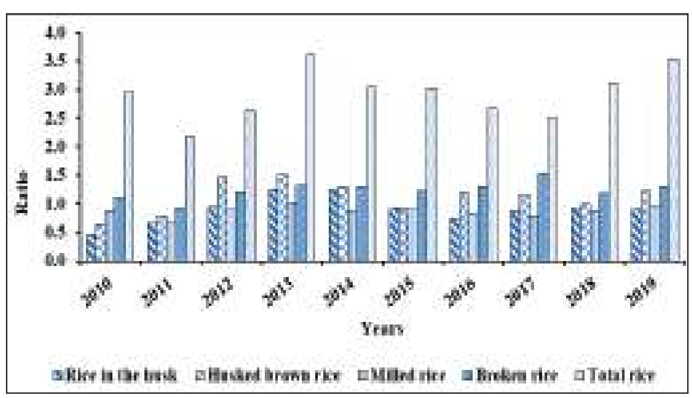

Figure 3. Ratio of unit price of world rice export to India's rice export

Table.2 Rice exports and prices at global level and from India during 2010-2019

Parameters	World			India			India's share in	
	Trade Qty (million tons)	Trade Value (Million US$)	Unit value (US$/ton)	Trade Qty (million tons)	Trade Value (Million US$)	Unit value (US$/ ton)	Quantity of world rice export (%)	World rice export Trade Value (%)
Rice in the husk (Paddy/rough)								
Minimum	2.01	710.67	325.63	0.02	13.20	340.83	0.62	1.31
Maximum	3.10	1072.49	430.92	0.25	90.73	788.14	9.70	10.46
Average	2.55	918.74	360.81	0.17	63.07	372.88	6.64	6.86
SD	0.30	119.99	41.76	0.09	27.40	149.47	3.19	2.95
Husked (brown) rice								
Minimum	1.53	898.49	474.65	0.0001	0.09	356.39	0.01	0.01
Maximum	4.44	2107.17	687.96	0.11	45.63	753.16	5.13	3.40
Average	2.58	1487.62	576.47	0.03	12.21	469.17	1.01	0.82
SD	0.84	361.78	75.32	0.03	13.79	134.48	1.54	1.02
Semi-milled/wholly milled rice, whether/not polished/glazed								
Minimum	27.34	16714.28	529.12	2.49	2282.45	558.28	9.10	13.66
Maximum	36.41	22158.44	665.88	10.72	7754.82	916.76	31.22	35.98
Average	32.89	19740.15	600.19	8.54	5838.15	683.51	25.97	29.58
SD	2.83	1786.54	48.41	2.69	1683.55	112.72	7.23	7.11
Broken Rice								
Minimum	2.97	1150.55	341.31	0.0002	0.07	278.05	0.01	0.01
Maximum	5.69	1942.98	455.86	1.3676	421.24	414.71	27.88	23.73
Average	4.37	1652.09	377.85	0.78	235.61	301.47	17.88	14.26
SD	0.90	230.52	39.12	0.46	140.69	39.15	9.24	7.69
Total Rice								
Minimum	34.55	19769.85	502.61	2.51	2295.81	536.54	7.25	11.61
Maximum	48.72	26439.88	627.61	12.12	8169.52	915.86	27.81	31.79
Average	42.39	23798.61	561.43	9.52	6149.05	646.04	22.45	25.84
SD	4.23	2132.44	45.63	3.17	1819.31	119.17	6.46	6.28

Table 3. Share of different types of rice in total India's rice exports quantity and value (%)

Year	Paddy quantity	Brown Rice quantity	Milled rice quantity	Broken rice quantity	Paddy value	Brown Rice value	Milled rice value	Broken rice value
2010	0.67	0.00	99.32	0.01	0.58	0.00	99.42	0.00
2011	0.77	0.05	94.83	4.34	0.58	0.04	97.79	1.59
2012	2.38	1.07	88.27	8.28	1.40	0.74	93.18	4.67
2013	2.12	0.22	88.74	8.92	1.01	0.16	94.92	3.90
2014	1.63	0.51	89.52	8.34	0.79	0.33	95.35	3.54
2015	1.82	0.14	87.65	10.40	1.14	0.14	93.68	5.04
2016	1.05	0.15	91.44	7.36	0.89	0.15	95.15	3.82
2017	1.38	0.09	88.45	10.07	0.88	0.12	93.77	5.23
2018	2.08	0.09	86.11	11.72	1.24	0.10	92.93	5.73
2019	2.52	0.10	94.21	3.17	1.32	0.05	97.30	1.33
Average	1.78	0.27	89.74	8.21	1.03	0.20	94.94	3.83

Dynamics of rice exports from India

Dynamics of Indian rice exports was analysed and found that the share of top 5 importing countries of rice from India was above 50 per cent in the case of paddy, brown rice and broken rice quantity in all 10 years under consideration **(Table 4)**. Only in the case of milled rice quantity, the top 5 countries share was below 50 per cent in 7 out of 10 years considered. There was no consistent pattern in top 5 importers share in value of rice import from India. When compared to the year 2010, in 2019, top 5 countries share increased in the case of paddy quantity, but declined in the case of brown rice, milled rice and broken rice. Over the decade as top 5 importers, totally 17 countries were involved in paddy imports from India. The corresponding number of countries was 21, 12 and 18 in case of brown rice, milled rice and broken rice, respectively against maximum possible value of 50 countries (10*5). Thus in the case of milled rice, less dynamics (in terms of number of countries involved as top 5 importers) is coupled with declining share of top 5 countries imported quantity. Dynamics of Indian Rice exports in terms of Basmati vs non-basmati also was analysed (**Table 4**). In all the ten years share of top 5 importers in quantity of rice import was above 50 per cent in case of basmati

Table 4. Share of top five destination countries in India's rice exports

year	Rice in husk		Brown rice		Milled Rice		Broken Rice	
	Quantity (%)	Trade Value (%)	Quantity (%)	Trade Value (%)	Quantity (%)	Trade Value (%)	Quantity (%)	Trade Value (%)
2010	94	94	99	99	85	85	96	96
2011	94	94	59	52	60	67	87	82
2012	79	55	98	97	44	49	84	83
2013	79	64	93	91	50	58	86	85
2014	96	89	95	94	41	46	86	85
2015	97	90	70	69	40	46	88	87
2016	97	92	74	74	43	49	87	86
2017	99	95	64	65	39	43	87	86
2018	99	96	78	81	41	47	84	83
2019	100	99	93	86	44	54	76	72
	Number of countries involved as top 5 countries in the 10 years							
	17		**21**		**12**		**18**	
	Basmati rice		**Non-basmati**					
	Quantity (%)	**Trade Value (%)**	**Quantity (%)**	**Trade Value (%)**				
2010-11	84	83	74	66				
2011-12	71	71	47	46				
2012-13	69	69	49	46				
2013-14	75	75	46	42				
2014-15	70	69	47	43				
2015-16	71	70	45	40				
2016-17	69	68	43	39				
2017-18	67	67	53	50				
2018-19	73	72	41	37				
2019-20	71	70	43	40				
	Number of countries involved as top 5 countries in the 10 years							
	7		14					

rice. In case of non-basmati rice, only in 2 years' top 5 importers share was above 50 per cent. But, in the case of both basmati and non-basmati rice, top 5 importers share declined in 2019-20 compared to 2010-11. Across the ten years, 7 countries were involved as top 5 importers in the case of basmati against 14 countries in the case of non-basmati rice.

Economic water productivity and virtual water trade from India through rice exports

Mekonnen and Hoekstra (2010) estimated water footprint (cubic meter of water per unit of output) of different crops and crop products for the period 1996 to 2005 for 113 countries. In the case of rice and rice products, India stood at 50th place indicating 49 countries were above it with lower Water Footprint (WF). The WF for selected four rice types/products in the case of India as well at global level indicated that the WF of Indian rice products is more than global level WF by 1.24 times (**Table 5**). Using these WF metrics, total WF of Indian rice exports and global rice exports during 2010-2019 are computed and presented in **Table 6**. On average India's share in virtual water trade of world rice exports was 8.22, 1.25, 32.13 and 22.12 per cent in the case of paddy (rice in husk), brown rice, milled rice and broken rice, respectively (**Figure 4**). This is more than corresponding share in quantity of rice exports as well as share in value

Table.5 Water footprint of different rice types

Product description	Water foot print (M^3/Ton)	
	Global average	India
Rice in the husk (paddy or rough)	1673	2070
Rice, husked (brown)	2172	2688
Rice, semi-milled or wholly milled, whether or not polished or glazed	2414	2986
Rice, broken	2497	3089

Source : Mekonnen, M.M. and Hoekstra, A.Y. (2010) The green, blue and grey water footprint of crops and derived crop products.

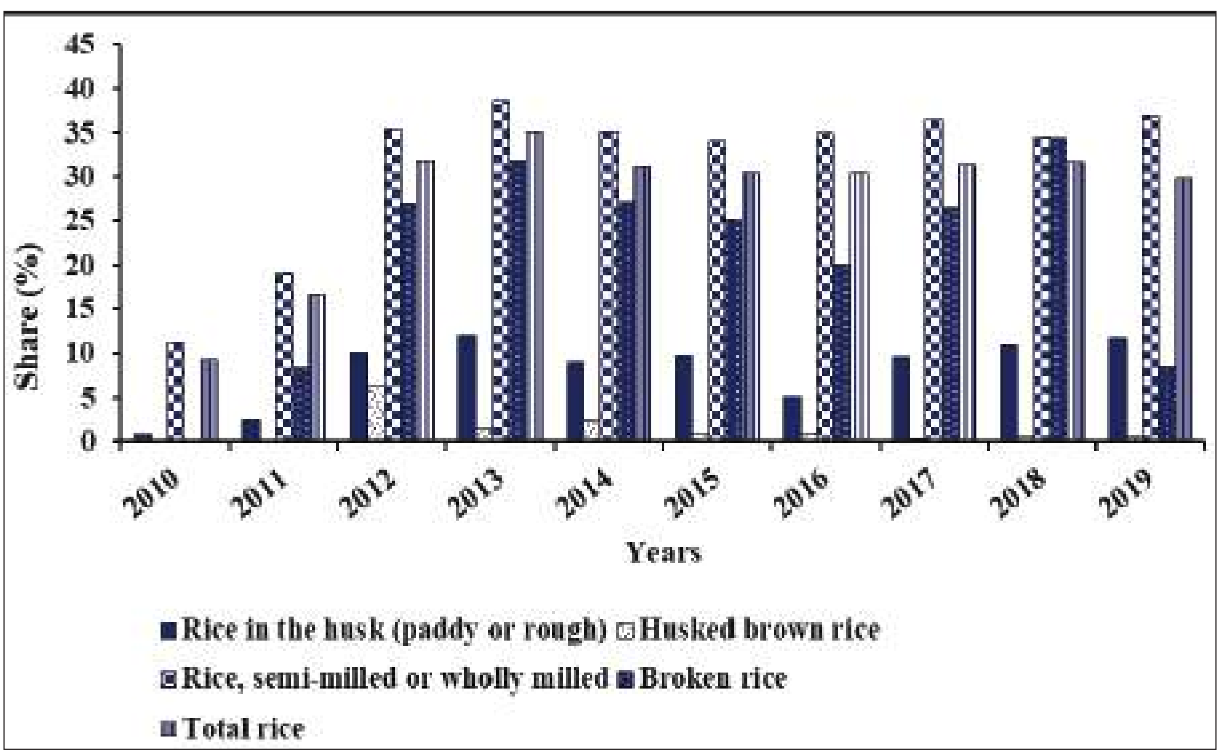

Figure 4. India's share in water footprint of rice exports at global level

of rice exports (**Table 2**). This indicates lower water use efficiency of Indian rice exports. Mekonnen and Hoekstra (2014) showed that small WFs are not inherent to high income countries or humid regions and the large WFs are not intrinsically connected to low income countries or arid regions. Hence, there is possibility to decrease WF through proper water management (like System of Rice Intensification (SRI), Alternate Wetting and Drying (AWD) etc., and through adoption of water saving technologies (like drip and sprinkler irrigation) in India also.

There are some criticisms regarding the concept of WF. Water Footprint considers only the volume of water used in production and hence not sufficient indicators of the benefits or cost of water use in any setting (Wichelns, 2015). Hence, to overcome this deficiency (at least partially) economic water productivity of Indian rice exports is computed in this study and contrasted with economic water productivity of rice exports at global level (**Table 6**). Economic water productivity of Indian rice exports in 2010-2019 decade ranged between 0.16 to 0.38 US$ per cubic meter in the case of paddy (Husked rice). The corresponding ranges were 0.13 to 0.28, 0.19 to 0.31 and 0.09 to 0.13 US$ per cubic meter in the case of husked brown rice, milled rice, and broken rice, respectively. In the decade under focus, maximum value of economic water productivity across all four types of rice exported was observed in the year 2010. However, across the four types of rice exported, the year in which minimal economic productivity observed was not the same year. In the period under focus the economic water productivity of rice exports at global level was higher than Indian level, in 7, 8,8,10 years in the case of paddy, brown rice, milled rice and broken rice, respectively (**Figure 5**). This once again indicates lower water use efficiency of rice exported from India.

Table.6 Economic water productivity in rice exports during 2010-2019

Parameters	World		India	
	Total water print (Gm3)	Economic water productivity (Us $/m3)	Total water print (Gm3)	Economic water productivity (Us $/m3)
Rice in the husk (paddy or rough)				
Minimum	3.37	0.19	0.03	0.16
Maximum	5.19	0.26	0.52	0.38
Average	4.26	0.22	0.35	0.18
Husked (brown) rice				
Minimum	3.31	0.22	0.0003	0.13
Maximum	9.64	0.32	0.30	0.28
Average	5.61	0.27	0.07	0.17
Rice, semi-milled or wholly milled				
Minimum	66.01	0.22	7.44	0.19
Maximum	87.90	0.28	32.02	0.31
Average	79.39	0.25	25.51	0.23
Broken rice				
Minimum	7.42	0.14	0.0005	0.09
Maximum	14.21	0.18	4.22	0.13
Average	10.92	0.15	2.41	0.10
Total Rice				
Minimum	81.28	0.21	7.47	0.18
Maximum	115.39	0.27	36.17	0.31
Average	100.17	0.24	28.34	0.22

* water productivity average is weighted average

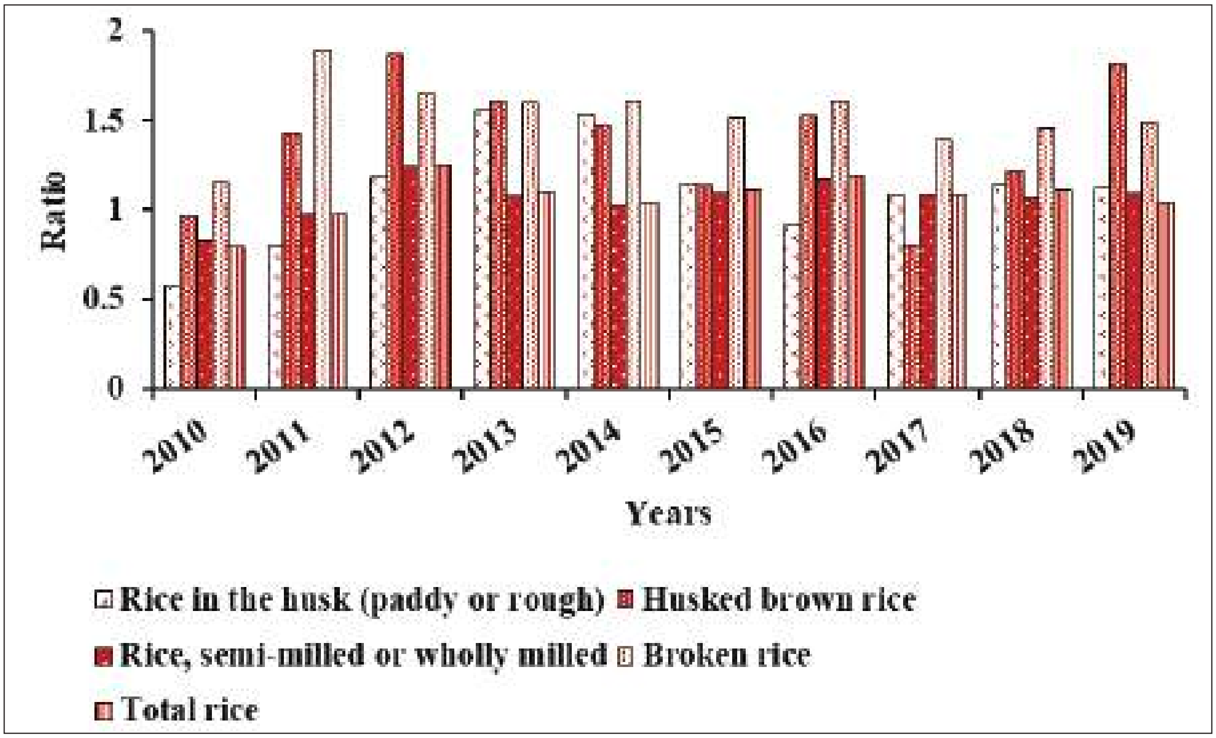

Figure 5. Ratio of economic water productivity of world to India in rice exports

Economic water productivity was also analysed for basmati and non-basmati rice exports separately using a water foot print of 4545 and 2986 m^3 per ton of rice respectively. Across the years (2009-10 to 2019-20) economic water productivity of Basmati rice exports ranged between 10.72 to 17.17 Rs per cubic meter of water against 7.24 to 9.54 Rs per cubic meter of water in non-basmati rice exports **(Table 7).** Economic water productivity of total (basmati and non-basmati) rice exports ranged between 9.16 to 12.86 Rs per cubic meter of water. In all the years under consideration, ratio of economic water productivity of basmati rice exports to Non-basmati rice exports from India was greater than one but this was lower than the ratio of unit value of basmati rice exports to unit value of non-basmati rice exports. Economic water productivity of rice in domestic sale at Minimum Support Price (MSP) ranged between 5.07 to 9.21 Rs per cubic meter of water. Hence the margin in total rice exports in terms of economic water productivity ranged between 2.59 to 6.42 across the years (2009-10 to 2019-20). However, the margin in case of non-basmati rice exports alone in terms of economic water productivity ranged between 0.33 (in 2019-20) to 3.44 (in 2009-10) Rs per cubic meter of water. These results are in line with Gawel and Bernsen (2013) argument that a water scarce but land rich country will export water intensive commodities only as long as the scarcity value of domestic water as an input in agriculture remains lower than the scarcity value of water in the importing country.

Gawel and Bernsen (2013) indicated that a water scarce country may have higher water productivity in certain crops than in a water rich country. India exported paddy to 17 countries as top 5 destinations in the decade 2010-2019. In this case, out of 50 instances (*i.e.*, top 5 countries in 10 years) in 29 instances (*i.e.*, 58 per cent instances) paddy export was to countries with lower water foot print (*i.e.*, countries with higher water use efficiency compared to India). In case of husked brown rice, milled rice, and broken rice such instances of exporting to countries with lower water foot print was 56, 22 and 26 per cent, respectively.

Novo *et al.*, (2009) observed that Spanish international trade with grains during 1997-2005 as net virtual water importer was consistent with *relative water scarcity*,

Table.7 Economic water productivity in basmati and non-basmati rice exports (Rs/M³)

Year	Economic water productivity of basmati rice	Economic water productivity of non-basmati rice	Economic water productivity of total rice	Ratio of economic water productivity of basmati rice to non-basmati rice	Domestic water productivity at MSP	Margin in exports of basmati rice	Margin in exports of non-basmati rice	Margin in exports of total rice
2009-10	11.88	8.77	11.74	1.36	5.33	6.55	3.44	6.42
2010-11	10.72	7.69	10.64	1.39	5.07	5.65	2.62	5.56
2011-12	10.73	7.26	9.16	1.48	5.48	5.24	1.78	3.68
2012-13	12.34	7.24	9.49	1.71	6.34	6	0.89	3.14
2013-14	17.17	8.34	12.26	2.06	6.65	10.52	1.69	5.61
2014-15	16.4	8.28	11.58	1.98	6.9	9.5	1.38	4.68
2015-16	12.36	7.93	10.1	1.56	7.15	5.2	0.77	2.95
2016-17	11.88	8.42	10.05	1.41	7.46	4.43	0.96	2.59
2017-18	14.58	8.89	11.26	1.64	7.86	6.71	1.03	3.4
2018-19	16.35	9.29	12.62	1.76	8.88	7.47	0.41	3.74
2019-20	15.32	9.54	12.86	1.61	9.21	6.11	0.33	3.65

as net imports increased in dry years. Debaere (2014) observed that water is indeed a source of comparative advantage and that countries that have more water available per capita tend to export more water-intensive goods. But contrary observations were made by Mohammad *et al.*, (2020), and Chen *et al.*, (2021). Yang *et al.*, (2003) examining the relationship between water scarcity and induced cereal import, estimated a water resource threshold with respect to cereal import as 1500 m^3/capita. According to them, below the threshold, the demand for cereal import increases exponentially with decreasing water resources. They predicted that in India, renewable fresh water falls below the threshold by the year 2030. But by 2017 itself renewable water resource available per capita in India fell to 1427 m^3. Thus *India is not a water rich country*, but still India is exporting rice. According to Key and Runsten, (1999) contract farming, together with lack of optimal water management policies also sometimes lead to situation wherein water scarce countries end up exporting virtual water to more productive developed nations.

Gawel and Bernsen (2013) argued that realigning virtual water trade flows according to notions of global water use efficiency is contradictory to economic efficiency concepts. Debaere (2014) opined that measure of country's available renewable freshwater per capita should be a better proxy of the true (opportunity) cost of water than the actual water prices consumers and producers pay. Countries comparative advantage hinges on both the variation of factor intensities among sectors and on the relative factor abundances across countries (Debaere, 2014; Fracasso, 2014). Keeping this observation in view, analysis was carried out focussing on India's top 5 rice export destination countries. Totally 47 countries were top 5 destinations in the period 2010-2019 across 4 types of rice/rice product exports. These 47 countries were categorized into 4 categories along two dimensions *viz.*, Renewable Water Resource Available Per capita (RWRAP) in 2017 and share of Agricultural Water Withdrawal in Total Water Withdrawal (AWWTWW) in 2017, keeping India as a reference country. In case of India, renewable water resource available per capita and share of agricultural water withdrawal in total water withdrawal in the year 2017 was 1427 m^3 and 90.41 per cent, respectively (FAO-AQUASTAT).

Out of 47 countries under focus, in 32 countries (*i.e.*, 68% of countries) RWRAP was more than India's RWRAP (**Table 8**). Out of these 32 countries, in 8 countries AWWTWW was more than India's AWWTWW (first quadrangle). Thus in these 8 countries water value may be more in other crops compared to rice. In the rest 24 countries, economic water scarcity (with higher value of water in other sectors) might led to lower AWWTWW (second quadrangle). Nepal and Vietnam (which were consistently in the list of top 5 importers of paddy), Iran (which was consistently in the list of top 5 importer of milled rice) and Senegal (which was consistently in the list of top 5 importer of broken rice) were having both RWRAP and AWWTWW greater than India. United Kingdom (which was consistently in the list of top 5 importer of brown rice) was having RWRAP higher than India, but AWWTWW lower than India. In Bangladesh which was having RWRAP higher than India, but AWWTWW lower than India, three fourths of freshwater withdrawal was for paddy irrigation. But nearly 39 per cent of water was over irrigated in paddy (Islam *et al.,* 2021).

Out of 15 countries in which RWRAP was less than that of RWARAP of India, in 3 countries (Ethiopia, Pakistan and Yemen) AWWTWW was more than AWWTWW of India (Third quadrangle). In these 3 countries too, water value may be more in other crops compared to rice. In case of Yemen, it is reported that a policy of subsidizing import of grains together with promoting high value crop cultivation was pursued (Ward, 2000). Thus, only in 12 out of 47 (top 5) destinations of Indian rice export, *i.e.,* 26 % countries, both RWRAP and AWWTWW was below that of India. United Arab Emirates (a consistent importer of brown rice and milled rice from India) and Saudi Arabia (a consistent importer of milled rice from India) were the countries appearing in the 12 countries group. Seven countries which were involved as top 5 basmati rice importers from India, were spread across all four quadrangles with maximum number (3 *i.e.,* Kuwait, Saudi Arabia and United Arab Emirates) in quadrangle four (**Table 8**). This is quite natural phenomenon as Basmati rice is a special type rice produced in India, wherein consumer preference is the underlying driver of trade. However, 14 countries involved as top 5 importers of non-basmati rice from India were also spread across all four quadrangles with maximum number of countries in quadrangle 2.

Besides water availability, arable land availability/ scarcity may also drive agri-food trade. In case of Japan (a water rich country) it is scarcity of land that shaped country's food import policies (Oki and Kanae, 2004). Kumar and Singh (2005) observed that virtual water exports increased with increase in gross cropped area because (i) access to arable land increases the ability to utilize available blue water for irrigation and (ii) increasing access to arable land improves the access to water held in the soil profile as "free good". In the current context, out of 47 countries (which were top 5 importers of four different rice types from India) in 25 (*i.e* in 53%) countries, per capita arable land available was lower than that of India (0.1181ha). Out of these 25 countries, 14 countries were with RWRAP greater than RWRAP of India. Overall out of 47 export destinations of rice exports from India under consideration, only 11 export destination countries were both water scarce and land scarce countries (compared to India). These observations are in line with previous reports that not all countries import food because of water scarcity (Yang *et al.,* 2003; Yang *et al.,* 2006; Verma *et al.,* 2009; Gawel and Bernsen, 2013)**.** Chen *et al.,* (2021) observed that most countries with low per capita land were net importers of embodied land while many countries with extreme water shortage were net exporters of virtual water. Thus global trade encouraged optimal distribution of land resources but exacerbated the uneven distribution of water resources. Mohammad *et al.,* (2020) showed that less developed countries that lack capital may end up specializing in water-intensive agricultural goods, even if their water resources are not plentiful.

Table.8 Water resource availability, water use in agriculture and arable land availability in India’s top five rice export destination countries in 2017

	Renewable water resource per capita >India				Renewable water resource per capita <India			
	Country	**Total renewable water resources per capita (m3/ inhabitant/ year)**	**Agricultural water withdrawal as % of total water withdrawal (%)**	**Arable land (hectares per person)**	**Country**	**Total renewable water resources per capita (m3/ inhabitant/ year)**	**Agricultural water withdrawal as % of total water withdrawal (%)**	**Arable land (hectares per person)**
	India	1427	90.41	0.12				
	First Quadrangle				**Third Quadrangle**			
Agricultural water withdrawal % of total water withdrawal >India	Bhutan	104619	94.08	0.14	Ethiopia	1147	91.84	0.15
	Iran	1699	92.18	0.18	Pakistan	1187	93.98	0.15
	Iraq	2393	91.49	0.14	Yemen	75	90.74	0.05
	Madagascar	13179	95.89	0.14				
	Nepal	7607	98.14	0.08				
	Senegal	2527	92.98	0.21				
	Timor-Leste	6608	91.38	0.13				
	Viet Nam	9346	94.78	0.07				
	Second quadrangle				**Fourth Quadrangle**			
Agricultural water withdrawal % of total water withdrawal <India	Australia	20013	63.43	1.9	Bahrain	78	33.31	0
	Bangladesh	7684	87.82	0.05	Burkina Faso	703	51.43	0.32
	Belgium	1602	1.13	0.07	Djibouti	318	15.79	0
	Benin	2361	25.21	0.25	Egypt	596	79.16	0.03
	CÃ´te d’Ivoire	3443	51.64	0.12	Kuwait	5	62.27	0
	Gambia	3614	38.58	0.2	Oman	300	85.84	0.01
	Guinea	18728	51.04	0.26	Qatar	21	31.96	0.01
	Guinea-Bissau	17176	75.79	0.17	Rep. of Korea	1364	58.93	0.03
	Indonesia	7628	85.21	0.09	Saudi Arabia	73	82.23	0.11
	Italy	3153	49.73	0.11	Singapore	105	4	0
	Liberia	49338	8.43	0.11	South Africa	901	58.77	0.22
	Malaysia	18647	45.65	0.03	United Arab Emirates	16	82.84	0
	Mauritius	2176	55.84	0.06				
	Mozambique	7578	73.05	0.2				
	Netherlands	5346	0.48	0.06				
	Nigeria	1499	44.17	0.18				
	Philippines	4554	73.28	0.05				
	Portugal	7523	78.43	0.09				
	Romania	10787	22.01	0.44				
	Russian Federation	31096	28.97	0.85				
	Spain	2390	65.22	0.27				
	Sri Lanka	2499	87.36	0.06				
	Togo	1909	34.08	0.35				
	United Kingdom	2203	14.05	0.09				

Source: FAO STAT

Economics of methane emission associated with rice exports from India

As observed in previous paragraphs share of Indian rice exports in total Indian rice production ranged between 2.42 to 11.31 per cent across years. Accordingly, methane emission associated with rice trade ranged between 2.42 to 11.31 per cent of total methane emission from rice production in India.

According to FAOSTAT methane emission per ton of rice in India ranged between 33.6 to 39.5 Kg per ton of rice production during 2009 to 2017. Sapkota *et al.*, (2019) reported emission of methane from paddy cultivation in range between 1425 to 6335 kg CO_2 per ha (across different states of India) with a mean value of 3188 Kg CO_2 per hectare in the year 2012. Thus, with average production of rice of 2.43 tons per ha (in 2012), carbon emission works out to be 1311.93 Kg per ton of rice *i.e.*, 62.5 Kg methane per ton of rice production (with GWP *i.e.* Global Warming Potential of methane = 21). According to India's second biennial update report to the United Nations Framework Convention on Climate Change, methane emission worked out to be 33 kg per ton of rice production in 2014 (BUR, 2019). According to GHG platform India computation, methane emission per ton of rice ranged from 30.9 to 38.4 kg between 2005 and 2015, with declining emission intensity over years. These wide variations were due to different time periods considered as well as due to differences in computational methods. FAOSTAT data is based on single emission factor (10.556 g methane per square meter area); on the other hand, GHG platform estimates are based on ecology specific emission factors. Sapkota *et al.*, (2019) estimated methane emission using farm level data with "Cool farm tool".

Using IPCC method (following GHG platform India) thereby using different emission factors for different rice ecosystems, methane emission and in turn carbon dioxide (CO_2) emission associated with Indian rice exports were computed in the current study. These methane emissions were converted into carbon equivalent by using a GWP factor of 21(IPCC,1995) for comparing with other study results. Using IMF bench mark of 75 US$ carbon price per ton of CO_2 (Parry *et al.*, 2021), carbon costs associated with rice exports (US$ per ton of rice) from India are computed. These costs worked out to be 4.68 to 5.2 per cent of unit value of export in the case of basmati rice (**Table 9**). Carbon costs share in unit value of exports ranged between 9.65 to 13.48 in the case of non-basmati rice and 4.84 to 8.79 per cent in the case of (Basmati + Non-basmati) rice exports in different years, indicating the possible increase in price of exports if carbon pricing is implemented in practice. If GWP factor of 28 (IPCC,2014) is used, the carbon taxes/costs will further increase. Hence carbon taxes if implemented may affect production, trade competitiveness, trade extent, trade pattern (Dumortier and Elobeid, 2021, Chayun 2020). Codjo *et al.*, (2021) in the context of Benin, reported that consumers in general were price sensitive and substitution between imported and domestic rice was limited. Implementation of carbon price unilaterally may lead to squeeze in margin of producers and carbon leakage. Already squeeze in margin of Indian farmers from rice exports due to some policies in rice importing countries was reported by Kumar (2019).

Among 47 trade partners identified as top 5 destinations of Indian rice exports, only with respect to 34 countries data pertaining to paddy harvested area and emission intensity is available in FAOSTAT database. Out of these 34 countries in 27 countries emission intensity was higher than that of emission intensity of India in 2017 (**Table 10**). But in these 27 countries paddy harvested area was lower than that of India. In the rest 7 countries, both emission intensity as well as paddy harvested area was lower than that of India. This indicates carbon leakage to some extent through rice exports from India.

India's projected rice supply in 2029 ranges from 138-145 million tons (NITI Ayog, 2018). OECD-FAO (2020) projects that India will export 14 per cent of its total rice production in 2029. Accordingly, share of trade led methane emission in total emission from rice production is expected to increase. However, over the years EI (Emission intensity in kg CO_2 equivalent per Kg product) in rice production in India is declining. EI of India in rice production was 1.5878 in 1961 declined

Table 9. Carbon cost of rice exports

Year	Methane Kg/ton rice	CO_2 equivalent per ton (in tons)	Carbon cost (US$ per ton rice)	Unit value US $/ton			Share of carbon cost in unit value (%)		
				Basmati	Non-basmati	Total rice	Basmati	Non-basmati	Total rice
2009-10	35.08	0.74	55.25	1180.78	572.50	1141.41	4.68	9.65	4.84
2010-11	34.09	0.72	53.69	1054.72	497.21	1031.63	5.09	10.80	5.20
2011-12	32.17	0.68	50.67	973.84	433.37	672.57	5.20	11.69	7.53
2012-13	31.15	0.65	49.07	1001.46	385.68	595.62	4.90	12.72	8.24
2013-14	31.11	0.65	48.99	1304.49	416.19	722.06	3.76	11.77	6.79
2014-15	31.17	0.65	49.09	1190.99	394.99	642.06	4.12	12.43	7.65
2015-16	30.84	0.65	48.58	855.08	360.37	552.42	5.68	13.48	8.79
2016-17	29.88	0.63	47.06	816.47	379.82	541.34	5.76	12.39	8.69
2017-18	28.78	0.60	45.33	992.33	397.82	587.72	4.57	11.40	7.71
2018-19	27.92	0.59	43.97	1070.58	399.75	647.61	4.11	11.00	6.79
2019-20	27.53	0.58	43.37	989.03	404.70	678.97	4.38	10.72	6.39

to 0.7067 in 2017 (FAOSTAT). Hence it is the larger area under paddy, which is contributing to higher methane emission from rice cultivation in India. The adoption of the System of Rice Intensification (SRI) resulted in emission reduction to the extent of 0.18 million tons of CO_2 equivalent during 2010-16 and Direct Seeded Rice (DSR) led to emission reduction of 0.17 million tons of Co_2 equivalent from 2014-16 (BUR,2015).

As of now in several countries carbon tax is limited to energy sector only but still having differential effect on competitiveness of different commodities (Chayun, 2020). Frank *et al.*, (2021) reported that there can be increase in global rice price to the extent of around 65% at global carbon tax of 150$ per ton of CO_2 equivalent on direct GHG emission across world regions and without consideration of adjustments in production system.

Options available to address environmental externalities

Nation level measures

Davis *et al.*, (2019) viewed that increasing the area under coarse cereals improves nutritional supply, increases climate resilience (fewer calories lost during an extreme dry year) reduces GHG emissions and demand for irrigation water and energy in India. However, as there is wide spatial variation in water footprint of rice within Indian states, change in crop planning such that total blue water footprint can be reduced can be a measure (Santosh *et al.*, 2021). Further import export policy of India should permit water intensive crops exports from the states where the blue WF are lower and the net gains from the international trade leads to positive virtual water balance and restrict exports from hotspot areas facing sustainability issues in water (Santosh *et al.*, 2021). Kumar (2019) observed that only in three states *viz* Punjab, Haryana and Tamil Nadu, export price of non-basmati rice was higher than economic costs consistently during 2013-14 to 2016-17. However, Chand *et al.*, (2021) observed that blue water footprint constituted over 70% of the total water footprint of rice in the irrigated north western zones of Punjab and Haryana. Hence they suggest incentivizing adoption of alternative technologies like Direct Seeded Rice (DSR), Alternate Wetting and Drying (AWD) and short duration water stress resistant rice varieties in these regions. Vetter *et al.*, (2017) reported that changing the water regime from continuously flooded to multiple drainage periods reduces methane emission by 9-fold. Gartaula *et al.*, (2020) reported potential of DSR and Machine transplanted rice in GHG mitigation in India. Promoting adoption of low carbon technologies (like SRI, AWD) through carbon premium/credit (incentive payment for reduced carbon emission) can be one policy option that need to be explored for not only reducing carbon emission but also water saving. For this water saving and reduced carbon emission through adoption of SRI or AWD or DSR in different rice ecosystems/zones/states need to be evaluated.

Table.10 Paddy area and emission intensity in paddy production in selected years in top five destinations of rice export from India

Country	Emission intensity (Kg CO_2 equivalent/kg product)		Paddy area (ha)		Paddy productivity (Kg/ha)	
	2010	2017	2010	2017	2010	2017
Australia	0.72	0.74	18931	82204	10390	9821
Bangladesh	0.69	0.7	11529000	11615000	4342	4662
Benin	0.44	0.26	47058	78969	2656	3529
Bhutan	0.87	0.67	22815	21202	3140	4074
Burkina Faso	2.88	2.98	133737	165086	2024	1972
CÃ´te d'Ivoire	0.33	0.38	394868	813790	3055	2605
Egypt	0.92	0.85	459525	549688	9422	9025
Ethiopia	1.33	1.29	29866	53107	3027	2844
Gambia	4.77	7.07	86150	65854	1159	456
Guinea	2.31	2	1465953	1805878	1101	1217
Guinea-Bissau	0.83	0.96	100510	104923	2082	1573
India	**0.8**	**0.71**	**42862400**	**43774070**	3359	3849
Indonesia	1.12	1.08	11797000	11471000	5025	5181
Iran	1.29	1.17	563517	396877	4419	4929
Iraq	1.9	1.28	47974	54283	3248	4898
Italy	2.08	1.95	247700	234133	6122	6825
Liberia	0.39	0.36	251230	233590	1179	1060
Madagascar	1.12	0.98	1307043	730000	3625	4932
Malaysia	1.37	1.07	677884	685548	3636	3750
Mozambique	1.5	2.19	226593	325000	1137	425
Nepal	0.92	0.75	1481289	1552469	2716	3369
Nigeria	1.42	1.3	2432630	5627700	1839	1391
Pakistan	1.23	0.97	2365300	2900595	3059	3853
Philippines	2.13	1.95	4354161	4811808	3622	4006
Portugal	2.38	2.25	29120	28944	5845	6211
Rep. of Korea	0.84	0.81	892074	754713	6514	7003
Romania	5.43	8.08	12403	9125	4966	4746
Russian Federation	2.13	2.47	200878	185649	5280	5314
Senegal	0.49	0.48	147208	305934	4103	3306
South Africa	55.64	56.49	1184	1113	2588	2763
Spain	2.31	2.51	122184	107604	7594	7762
Sri Lanka	0.79	1.48	1060360	791679	4056	3010
Timor-Leste	1.35	1.39	36548	20681	3090	3107
Togo	0.24	0.29	47403	84395	2323	1665
Viet Nam	0.91	0.91	7489400	7708534	5342	5548

Other challenge in implementing carbon pricing in agriculture is measuring carbon emission/storage capacity at farm level on yearly basis. However, some studies (Folkhard *et al.,* 2021) are exploring ways to integrate agriculture into carbon pricing, by focusing on aggregate collection points of products. Potential of carbon credits in sustainable rice cultivation was also reported in the context of USA (Proville *et al.,* 2021), Sri Lanka (Razmy *et al.,* 2013), and practice of carbon credits in sustainable rice cultivation was reported by EDF (2019) in the context of USA.

Reducing subsidies in water stressed regions and strengthening rice procurement in eastern system is also being viewed as some measures to better planning of rice cultivation in India (Chand *et al.*, 2021). Batini (2019) suggests that Governments should make the adoption of on-farm conservation practices a condition for receiving farm subsidies. Breeding low-emitting rice varieties could be one effective mitigation strategy (Chirinda *et al.,* 2018; Balakrishnan *et al*., 2018).

International measures

Hoekstra (2011) argued that addressing water problems at the river basin level is not always sufficient. They identified four major issues to be addressed at global scale *viz*., efficiency, equity, sustainability and security of water supply in a globalized world. The possible arrangements that address these issues are (i) an international protocol on water pricing (ii) a pollution tax and international nutrient housekeeping (iii) water labelling of water intensive products (consumer perspective) or (Producer oriented) water certification of industries or retailers (iv) minimum water rights (v)maximum allowable levels of water use to be defined at basin level and aggregated at national level according to the philosophy of fair shares (vi) Implementing the water neutral concept(water offset by investing in water conservation measure or in water supply to the poor) (vii) International business code for multinationals in the water sector and tradable water footprint permits. According to the global water governance approach, local measures that include opportunity costs and environmental costs in agricultural water prices will not be successful. Several policy instruments have therefore been suggested like international water pricing protocol, virtual water border taxes, tradable water footprint permits. In the absence of global natural resource market, Chen *et al.,* (2021) opine that resource tax may be an effective means to reduce global environmental inequality and resource mismatch. Rosa *et al.,* (2019) view that in an increasingly water scarce world, Governments could take specific actions targeting unsustainable irrigation practices by penalizing the associated imports. By identifying trade links that are responsible for unsustainable virtual water trade, policies are needed to achieve sustainable water and food security goals in the coming decades. Cheptea and Dupraz (2021) observed that countries' irrigation behaviour is strongly linked to the global prices of crops, and the export price effect is stronger when countries are net exporters of irrigated crops. Accordingly, they suggest that trade policies like product specific export taxes or binding export quotas linked to the embedded irrigation water can be used as tools in water management.

Batini (2019) suggested that at International level, a fund could be setup to compensate countries for foregoing trade in commodities whose production threatens critical ecosystem. As under the UNFCCC (United Nations Framework Convention on Climate Change) countries are responsible only for emissions within their own borders, Parry (2019), Parry *et al.,* (2021) suggested carbon tax for reducing GHG emission. Further to reduce emissions to a level consistent with a 2 degrees C target, a global average carbon price of 75$ a ton was advocated (Parry, 2019; Parry *et al.,* 2021).

A contentious debate is going on regarding appropriate basis for GHG emission measurement *i.e.,* production based measurement vs consumption based measurement. Amidst this debate Bontems and Calmette (2019) proposed a new way of assessing environmental responsibility at the country level taking into account their trade balance in terms of carbon. For this, they examined the extent to which trade flows for a given country increases or decreases global emissions relative to the virtual situation where imports would have been produced in the consumer country. They argued that it would be fair for countries to retain responsibility for the additional emissions they create when trading. Compared to the consumer based rule, the modified rule will increase (reduce) a country's responsibility when it is creating more (less) emissions by exporting towards cleaner countries than by importing from less clean countries. Compared to pure producer based rule this will create incentives to reduce emission if and only if the country under scrutiny is a global net importer from less emission efficient countries. However, the modified rule diminishes the incentive to reduce emission when the country is a global net exporter towards less emission efficient countries. Compared to a pure consumer based rule, the modified rule always increases the incentive to reduce emission. Jakob *et al.*, (2021) proposed responsibility sharing for trade related emissions based on economic benefits from emitting free of charge (*i.e.*, when carbon emissions do not carry price). Under this proposal, a certain share of emission associated to import as well as exports will be assigned to each country. However, these studies (Bontems and Calmette, 2019; Jakob *et al.*, 2021) are focussing on aggregate emission or emission intensity per unit of GDP of countries in bilateral trade relationships but not related to any specific commodity.

Currently Emission Trading Systems (ETS) wherever operational are focusing only on non-agricultural sectors. According to Jennifer and Adam (2019), key objections to the inclusion of agricultural emissions in the ETS are the lack of effective mitigation technologies and the limited ability of farmers to pass the costs of compliance on to their predominately international customers. In this backdrop, Chirinda *et al.*, (2018) opined that increasing consumer awareness and influencing consumer preference towards more sustainably produced rice will contribute towards incentivizing the adoption of good management and technological choices.

Conclusions

It is evident that there are several technological and policy options available for reducing water use and GHG emission from rice production and trade. In some cases, these options become complementary. For instance, carbon premium/ credit policy can be used to accelerate adoption of technologies like SRI, DSR, AWD at country level. This will aid in not only reducing water consumption but also reduce GHG emission. But for implementing this option carbon saving due to adoption of these technologies need to be evaluated at different states/zone/ecosystem levels. Some trade policy instruments like carbon tax can also be used to influence rice trade extent and pattern. But while applying trade instruments, compliance with WTO rules must be ensured. Parry *et al.*, (2021) proposed International Carbon price floor among large emitter countries initially to fossil fuel sector but later extending to all sectors. Thus out of several options available, more economically feasible and accep table options need to be identified by in depth studies. Further, for addressing environmental externalities associated with rice trade, efforts at multi-country level are needed for effectiveness in line with "Climate Club " concept.

Limitations of the study: Heterogeneity across states in paddy Water footprint and methane emissions are not considered in the current study. Further in the study, focus is limited to methane emission only, other GHG gases are not considered. Further in calculation of water footprint and methane (Carbon) emission, contribution of transport was not accounted for.

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SHORT COMMUNICATION OPEN ACCESS

DRR Dhan 53 (RP-6113-Patho-BB9; IET 27294) - a high yielding, bacterial blight resistant, fine grain type rice variety

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Abstract

DRR Dhan 53 was released for commercial cultivation in Samba Mahsuri/Improved Samba Mahsuri growing regions of Telangana, Andhra Pradesh, Tamilnadu, Karnataka, Chhattisgarh, Orissa, Jharkhand, Bihar, Gujarat and Maharashtra by Central Sub-committee on Crop Standards, Notification and Release of Varieties in 2020. It is a cross between Improved Samba Mahsuri*3/PAU 3554. DRR Dhan 53 (IET 27294) is a marker assisted selection (MAS) derived product in the genetic background of Improved Samba Mahsuri. DRR Dhan 53 is a durable bacterial blight resistant, high-yielding, fine-grain type rice variety having the major bacterial blight resistance genes, Xa21+xa13+xa5+Xa38 with seed to seed maturity of 130-135 days and average yield of 5.5- 6 t/ ha.

Keywords: Xa 38, bacterial blight, medium slender, grain yield

Bacterial blight (BB) of rice caused by *Xanthomonas oryzae* pv. *oryzae* is one of the major production constraint especially in irrigated and rainfed lowland ecosystem in India. It is primarily a disease of monsoon season, of high yielding rice varieties grown under heavy nitrogen fertilization. Yield loss due to the disease may be as high as 50% or more depending on the variety, growth stage, extent of nitrogenous fertilizers applied, geographical location and seasonal conditions. Analyses of survey data of last 40 years has revealed that the disease has increased significantly in different rice growing regions of India. In last one decade, bacterial blight has appeared in epidemic proportion in several parts of South India causing significant yield loss in fine grain rice varieties like Samba Mahsuri (Laha *et al.,* 2016). As chemical control of the disease is not satisfactory, development and deployment of bacterial blight resistant rice varieties is the most important method of managing the disease. Even though, the rice variety, Improved Samba Mahsuri (possessing three bacterial blight resistance genes, *Xa21*, *xa13* and *xa5*) has shown good level of resistance against bacterial blight, at few locations it has shown only moderate resistance indicating evolution of new virulence forms of the pathogen. Therefore, DRR Dhan 53 was developed by adding a new gene, *Xa38* in the genetic background of Improved Samba Mahsuri to provide a higher level and broad spectrum resistance against bacterial blight of rice.

Parentage

It is a cross between Improved Samba Mahsuri*3/PAU 3554. DRR Dhan 53 (IET 27294) is a MAS derived product in the genetic background of Improved Samba Mahsuri. An additional '*Xa38*', a dominant, broad-spectrum bacterial blight resistant gene from the donor parent, PAU 3554 [PR 114 (Xa38)], is introgressed into bacteial blight resistant rice variety, Improved Samba Mahsuri through marker assisted backcross breeding (Yugander *et al*., 2018).

Characteristics of DRR Dhan 53

- DRR Dhan 53 is a MAS derived, durable bacterial blight resistant high-yielding, fine-grain type rice variety having the major bacterial blight resistance genes, *Xa21+xa13+xa5+Xa38* with seed to seed maturity of 130-135 days and average yield of 5.5-6 t/ ha.
- DRR Dhan 53 possesses medium-slender grain type with very good HRR (78.7%), intermediate amylose content (22.2), optimum GC (22) and intermediate ASV (5.0) and is comparable to the recurrent parent, Improved Samba Mahsuri in all the grain and cooking quality parameters.
- The variety exhibited highly resistant reaction to bacterial blight at different bacterial blight hot spot locations in India. In AICRIP trials, it exhibited an SI of 4.2 (2018) and 3.5 (2019) as compared to the recurrent parent, Improved Samba Mahsuri which showed SI of 4.6 (2018) and 3.9 (2018).
- In AICRIP trial, it recorded average yield advantage of more than 7% over the recurrent parent, Improved Samba Mahsuri.
- Based on background analysis, it has shown > 93 % recovery of recurrent parent genome and complete phenome recovery of the recurrent parent, Improved Samba Mahsuri.

Considering on par or better performance for yield, grain and cooking quality traits with the recurrent parent and added advantage of its resistance to bacterial blight, DRR Dhan 53 was released for commercial cultivation in Samba Mahsuri/Improved Samba Mahsuri growing regions of Telangana, Andhra Pradesh, Tamilnadu, Karnataka, Chhattisgarh, Orissa, Jharkhand, Bihar, Gujarat and Maharashtra by Central Sub-committee on Crop Standards, Notification and Release of Varieties in 2020.

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SHORT COMMUNICATION OPEN ACCESS

DRR Dhan 54 [IET 25653 (RP 5943-421-16-1-1-B)] – A new aerobic rice variety

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Abstract

DRR Dhan 54 [IET 25653 (RP 5943-421-16-1-1-B)] was released for aerobic system of cultivation in water limiting areas of Zone II (Haryana), III (Odisha, Bihar and Jharkhand), VI (Gujarat) and VII (Telangana) through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 500(E) dated 29th Jan 2021 [CG-DL-E-03022021-224901]. DRR Dhan 54 was developed from the cross of RP 5124-11-4-3-2-1/IR 78877-208-B-1-1. It was tested in Aerobic trials in AICRIP during 2015-2018 and found to be a top ranking entry on overall basis in three years (2018, 2016 and 2015). Across multiple zones, DRR Dhan 54 ranked 1st with 15.8%, 4th with 12% and 5th with 17% yield advantage over the BVC in 2018, 2016 and 2015, respectively indicating its wider adaptability and yield stability. It has desirable grain quality traits in terms of high HRR%, intermediate AC% and multiple pest and disease resistance.

Keywords: aerobic rice, water limiting areas, zone, yield, grain quality

DRR Dhan 54 [IET 25653 (RP 5943-421-16-1-1-B)] was released and notified through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 500(E) dt. 29th Jan 2021 [CG-DL-E-03022021-224901]. It is suitable for aerobic system of cultivation under water limiting conditions and recommended for growing in Zone II (Haryana), III (Odisha, Bihar and Jharkand), VI (Gujarat) and VII (Telangana). It was developed from the cross of RP 5124-11-4-3-2-1/IR 78877-208-B-1-1 using pedigree method of breeding. Superior segregants from the cross were selected in F_2 generation and single plant selection was practised till F_5 generation. Progenies were evaluated in F_5 generation for yield and other traits, yield trial was conducted in F_6 generation and promising line designated as RP 5943-421-16-1-1-B in the station trial, was nominated to AICRIP testing in IVT-Aerobic in 2015.

Performance across states: On overall basis, DRR Dhan 54 ranked 1st, 4th and 5th with 15.8, 12 and 17% yield advantage over the best varietal check (BVC) in 2018, 2016 and 2015, respectively indicating its wider adaptability and yield stability. In the notified states, it was evaluated at 18 locations during 2015-2018 and was a top ranking entry (among top 5) at 14 locations yielding 19.14, 24.94, 30.89% higher than national, zonal and local checks, respectively. It recorded superior performance with a yield advantage of 15.1, 22.6, 10.0, 10.6, 16.1 and 5.0% over the BVCs in Odisha, Bihar, Jharkhand, Telangana, Gujarat and Haryana, respectively.

Field view of DRR Dhan 54 A. Aerobic conditions-IIRR farm, *kharif* 2019, B. Transplanted conditions in farmer's field-*Rabi* 2021

Figure 2a. DRR Dhan 54-paddy (whole grain), 2b. Hulled rice, 2c. Polished rice

Zonal performance: In Zone II, DRR Dhan 54 ranked 3rd and 2nd with 6.4 and 13.8% yield advantage over BVC in 2018 and 2016, respectively. In Zone III, it ranked 3rd with 16.8, 11.0 and 38.0% yield advantage over BVC in 2018, 2016 and 2015, respectively and in Zone VI, it ranked 2nd and 1st with 14 and 30% yield advantage over BVC in 2018 and 2017, respectively.

Morphological distinguishable features: DRR Dhan 54 has thick and strong culm, medium green foliage and deflexed compact panicle with strong secondary branching. Mild pubescence is observed on lemma and tip of the lemma is yellowish. IET 25653 has short bold grain with high hulling recovery (78.1%), milling recovery (69.7%), a high head rice recovery (HRR) of 65.3% and desirable cooking quality traits in terms of intermediate amylose content (AC) (21.6%), GC of 44mm, ASV of 4.0, white kernel appearance and very occasional chalkiness **(Figure 2).**

Agronomic performance and biotic stress resistance: In nutrient management trials under aerobic system of cultivation, DRR Dhan 54 recorded significant response in terms of high % of germination (76.34%), vigor index (43.5), number of panicles per m^2 (487), test weight (25.11g), high spikelet fertility (89.36%) and yield (4.67 t/ha) with application of 150% of recommended dose of fertilizer (RDF) with N: 120-180 kg/ha, P: 40 kg/ha and K: 50kg/ha. It is resistant to leaf blast, sheath rot, RTD and false smut and moderately resistant to neck blast, bacterial leaf blight, brown spot, glume discoloration and stem borer.

Owing to its suitability under aerobic system of cultivation with high yielding performance under water limiting conditions, wider adaptability, multiple pest resistance and desirable grain quality traits, cultivation of DRR Dhan 54 would stabilize rice yields in the country under constrained water resources.

SHORT COMMUNICATION OPEN ACCESS

DRR Dhan 55 (IET 26194) - A high yielding, early maturing aerobic rice variety

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Abstract

DRR Dhan 55 [IET 26194(RP 5591-123-16-2)], an aerobic rice variety developed from MTU1010/ IR79915-B-83-4-3 cross combination. It was evaluated in AICRIP multi-location aerobic rice trials during wet seasons of 2016 to 2019. DRR Dhan 55 consistently out-performed the check varieties in Eastern Zone (Zone III) and Central Zone (Zone V) with a mean grain yield 4974 kg/ha, which is 15%, 19% and 18 % higher than National check, Zonal and Local checks, respectively. In addition, it exhibited moderate resistance to Leaf blast and Neck blast; and also resistance to gall midge and rice thrips; and moderate resistance to plant hoppers. DRR Dhan 55 has medium duration of 120-130 days (seed to seed) and possess desirable grain and cooking quality parameters. It was released for cultivation in aerobic ecosystems of Bihar (Zone III) and Chhattisgarh (Zone V) states through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 500(E) dt. 29th Jan 2021[CG-DL-E-03022021-224901].

Keywords: aerobic rice, resistance, grain yield, cooking quality

Rice (*Oryza sativa* L.) is cultivated in 22 million hectares under irrigated ecology which accounts about half of the total area under rice production in India. In view of climate change, limiting water and human resources, aerobic rice is the need of the hour for substantial and stabilized crop returns. Indian Institute of Rice Research (ICAR-IIRR) has initiated emphasis on aerobic rice and with concerted efforts started in 2011 with crossing of MTU 1010/ IR79915-B-83-4-3, the segregating populations were evaluated under direct seeded aerobic conditions. The promising line RP 5591-123-16-2 was identified and nominated in AICRIP Aerobic 2016 trial. Subsequently, the entry performed all the three years and released as new direct seeded aerobic rice variety DRR Dhan 55 through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 500(E) dt. 29th Jan 2021 [CG-DL-E-03022021-224901] suitable for cultivation in Bihar State of eastern zone (Zone III) and Chhattisgarh State of central zone (Zone V).

The overall mean grain yield of DRR Dhan 55 in Zone III and V was 4974 kg/ha, which is 15, 19 and 18 % higher than National check, Zonal and Local checks, respectively. The mean grain yield in Zone III was 4981 kg/ha, which was 17, 13, and 19% higher than National check, Zonal and Local checks, respectively. The mean grain yield in Zone V was 4958 kg/ha, which was 10, 36, 16 % higher than National check, Zonal and Local checks, respectively. The weighted mean grain yield was 5317 kg/ha in Bihar and this was > 10% higher than the best check. In Chhattisgarh state, the weighted grain yield mean was 4728 kg/ha and out yielded the national, regional and local checks by 18, 32 and 20 %, respectively **(Table 1).**

Table 1: Yield performance of IET 26194 in Zone III and Zone V regions

Zone/State	Mean Grain Yield (kg.ha^{-1})	Superiority over checks		
		National Check (%)	Zonal Check (%)	Local Check (%)
Z-III & Z-V	4974	15	19	18
Z-III	4981	17	13	19
Z-V	4958	10	36	16
Bihar	5317	7	8	15
Chhattisgarh	4728	18	32	20

It exhibited resistance to major insect pests and diseases such as leaf blast, neck blast, gall midge and rice thrips and moderate resistance to plant hoppers. It has good hulling (78.07%), milling (68.90%) and head rice recovery (55.53%) in comparison with the checks and qualifying varieties. It possesses intermediate amylose content (22.58), medium alkali spreading value (7.0), medium gel consistency (22mm), long bold grain type (KL- 6.22 mm; KB- 2.22 mm) and other desirable grain and cooking quality parameters **(Figure 1).**

Figure 1A. Field view of DRR Dhan 55, 1B. Grain, Brown rice and Polished rice view of DRR Dhan 55

The variety DRR Dhan 55 is highly suitable for dry direct seeded aerobic conditions with intermittent irrigation. Dry direct seeding is preferably during the second week of June to second week of July (with the onset of rain or with pre-sowing irrigation). Immediately after sowing, lifesaving irrigation should be ensured for uniform germination and crop establishment. Weed management is a big menace in aerobic rice. In order to resolve this, apply Pendimethalin herbicide @1 kg per hectare at field capacity moisture within 3 days of sowing. Further, it is recommended to apply Post Emergence, broad spectrum systemic herbicide like Bispyribac Sodium 10% SC (Nominigold) @50ml per hectare at field capacity moisture within 5-15 days of sowing. One intermittent weeding is recommended (two if more weeds) during crop growth period. Need based irrigation should be followed upto physiological maturity.

The DRR Dhan 55 has an advantage of 10-15 days (115-120 seed to seed duration) in comparison with transplanted rice and can yield up to 5-5.5t/ha subject to use under area of adoption and recommended climate conditions and adoption of package and practices. It is suitable for direct seeding of both early *Kharif* and *Rabi* seasons.

56th Annual Rice Group Meeting Report

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ICAR- All India Coordinated Research Project (AICRP) on Rice 56th Annual group meeting (56th ARGM) was held through video conferencing during 16-17 and 19-20 April, 2021. Center-wise individual presentations by AICRIP co-operators were held on April 16-17, 2021. All the cooperators in Zone II – Northern areas (6), Zone III – Eastern region (10), Zone IV – North eastern region (3), Zone V – Central region (4), Zone VI – Western region (3), Zone VII – Southern region (12) and ICAR institutes (5) presented the results of AICRIP trials conducted at their respective centers during *Kharif* 2020.

Inaugural session was held on 19th April 2021. The session was chaired by Dr. T Mohapatra, Secretary, DARE & DG, ICAR and co-chaired by Dr. YP Singh, ADG (FFC) and Dr. DK Yadava, ADG (Seeds). Dr. D Subrahmanyam, Director (Acting) presented the salient findings of AICRIP program and appreciated the efforts made by all the co-operators in conducting and sending the data to the extent of 84%, 74% and 100% by funded centers, voluntary centers and private sector, respectively, despite the COVID 19 pandemic situation. Dr. DK Yadava, ADG (Seeds) was impressed with the record rice production of 120.30 mt during 2020-21 and India becoming a leading exporter of basmati rice earning 50000 crore rupees of foreign exchange annually. He specifically mentioned the need for short duration high yielding rice varieties and reiterated the role of private sector in hybrid rice research and development. Prof. HS Gupta, Chairman, QRT recommended to provide one time grant from ICAR in order to improve the working facilities thereby enhancing output of AICRIP program operating not only at headquarters but also cooperating centres.

Dr. T Mohapatra, DG, ICAR appreciated the efforts of AICRIP program in conducting trials across length and breadth of the country. He emphasised the need to bring innovative changes in the current multi-location evaluation system of rice. Considering the yield levels reported in AICRIP trials, there is a need to set the benchmark yield levels ecosystem-wise so that varietal entries showing yield level above the bench mark will only be promoted. Multiple resistance/ tolerance against pests, diseases and abiotic stresses prevalent in the target area has to be given priority along with bench mark yield during promotion of varieties. He said that concerted efforts have to be made on processing and value addition in rice such as modification of starch, biofortification of rice with enhanced Zn and protein content at institutional level. He put forward a suggestion to identify and release crop production and crop protection technologies in addition to varietal technologies during AICRIP workshop followed by awarding certificates to the centres/Scientists for the technologies.

Technical session I included presentations by principal investigators of respective disciplines, *i.e.*, results of varietal trials of irrigated rice and breeder seed production by Dr AVSR Swamy, ICAR-IIRR, varietal trials of rainfed rice by Dr. BC Patra, ICAR-NRRI, hybrid rice trials by Dr. AS Hari Prasad, Agronomy trials by Dr R Mahender Kumar, Soil Science trials by Dr MBB Prasad Babu, Plant physiology trials by Dr P Raghuveer Rao, Entomology trials by Dr. B Jhansi Rani, pathology trials by Dr. MS Prasad. This was followed by Technical session II that included discipline-wise planning and finalisation of the technical programmes for 2021-22.

A special session was held on IRRI-ICAR collaborative programmes on 20th April 2021. The session was chaired by Dr. AK Singh, Director, ICAR-IARI and co-chaired by Dr Jean Balie, DG, IRRI. DG, IRRI briefed about the importance of IRRI–ICAR Collaborative programme and highlighted the importance of establishment of IRRI center at Varanasi and Hyderabad, India and promised that this center will cater the needs of rice research in India. He appreciated the efforts of ICAR in India to popularize and fine tune Direct Seeded Rice (DSR) technology. He stressed that the new rice varieties with high nutrition, high antioxidants will help in overcoming malnutrition. He also emphasized the potential of Rice Fallow system which covers huge area in eastern and north eastern states of the country. Dr Dipankar Maiti, Director, ICAR-NRRI briefed the important areas to be addressed in rice research like capturing the natural evolution present in the form of landraces, breaking the yield barrier, work on biotic stresses like false smut, BPH. Dr. D Subrahmanyam, Director, ICAR-IIRR emphasized the importance of sustainability of rice production system through improving nitrogen and water use efficiency, widening the genetic base, training of more number of scientists in cutting edge technologies. Dr. Sankalp Bhosale and Dr. Vikas K Singh have presented ONE RICE breeding strategy adopted by IRRI to achieve higher genetic gain with limited period. Dr Nese Sreenivasulu presented Rice and Nutrition – Myths and Truths. He explained about the importance of balanced diet globally to address malnutrition and obesity. Dr. Pavan Kumar Yeggina presented on GIS and RS based mapping application for monitoring rice-fallow and crop losses for the insurance coverage. He covered the geospatial techniques for mapping and characterizing the rice fallow areas in Assam and Odisha.

Another special session was held on Impressions and recommendations of QRT. Dr HS Gupta, Chairman, QRT Committee complimented the AICRIP system for enabling India to become the largest exporter of rice and phenomenal raise in export earnings. He has given the following recommendations for improvement of IIRR and AICRIP:

1. IIRR & AICRIP together have done a commendable job but there exists enormous scope for further improvement that will translate in the outcome by meeting the targets which are dynamic though.

2. Rice area should be reduced to 42 m.ha. in 2030 & 40 m.ha. in 2050
3. Infrastructure is ~50 yrs. old and needs renovation
4. Dissemination of technology to be strengthened in Central and Eastern zones
5. Value chain & export of Red/black rice to be strengthened
6. International Collaborations *e.g*. CGIAR centers should align their research priorities with those of the host country and train scientists in latest technologies. Varanasi center of IIRRI should shoulder specific responsibility for assistance in research relevant to eastern India.
7. Business as usual will not do - bring in disruptive changes 8. If right assistance is provided at right time, IIRR & AICRIP – a time tested institution, can turn around rice research of India
8. In the State Varietal Release Committee meetings, the Director, ICAR-IIRR (representing ICAR) or his nominee has to be essentially be included as member of SVRC to ensure proper scrutiny of the proposal.

Plenary session was chaired by Dr. AK Singh, Director, ICAR-IARI and co-chaired by Dr. YP Singh, ADG (FFC), Dr. D Maiti, Director, ICAR-NRRI and Dr. D Subrahmanyam, Director (Acting), ICAR-IIRR. Technical program for 2021-2022 was presented by respective PI's of various disciplines. The following recommendations emerged after thorough deliberations:

1. Funded centres should take utmost care while conducting the trials and furnishing data. The centres that failed to conduct as well as provide trial data should be dropped from AICRIP system.
2. It is required to set up benchmark yield levels ecosystem-wise and the entries with yield levels above the bench mark should only be promoted.
3. Production Oriented Survey (POS) has to be utilized while formulating action plan of AICRIP. A review would be made in the forthcoming Annual Rice Group Meeting for examining the percolation of POS in action plan.
4. Nitrogen use efficient rice lines must be integrated into breeding programs to generate high yielding elite lines insulated with high nitrogen use efficiency. Similarly export oriented research in sticky rice should be initiated in AICRIP to expand the export potential.
5. A critical analysis has to be undertaken in AICRIP - Soil science to formulate the trials for estimating the effect of Nano fertilizers and silicon spray in saving 20 to 30% of fertilizer usage.
6. It is necessary to introgress a combination of resistant/tolerant genes/QTLs for various biotic and abiotic stresses keeping in view the requirement of target locations while developing MAS products.
7. It is essential to identify and release crop production and crop protection technologies in addition to varietal technologies during AICRIP workshop followed by awarding certificates to the centers/Scientists for the technologies.
8. The novel genetic stocks exhibiting moderate resistance particularly for complex pests and diseases such as BPH, WBPH and False smut should also be registered with NBPGR as donors since they confer durable and stable resistance.
9. There is need to quantify the benefits of water saving technologies like aerobic rice, Direct Seeded Rice (DSR) and Alternate Wetting and Drying (AWD) in terms of saving labour and water compared to conventional transplanting. It is suggested to estimate the yield penalty, if any and how we manage the yield penalty in these water saving technologies.

10. It was suggested to prepare documents on yield gap analysis and nutrient use efficiency of rice cultivars from past decade's AICRIP research work and application in breeding program.

11. To formulate research programs mainly to reduce production cost by use of herbicides and mechanisation in direct seeding/ transplanting, weeding, harvesting and other operations.

12. Majority of centres are evaluating the AICRIP entries against insect-pests and diseases under natural /artificial inoculation conditions. It was suggested that the artificial inoculation and creating sufficient insect-pest load or disease pressure is compulsory in screening trials under field or poly-house conditions.

13. Establishment of misting facility for Uniform Blast Nursery (UBN) at AICRIP centres and Rapid Diagnostic Kits for major diseases need to be developed.

14. Generation of new crop protection technologies and broadening of genetic base to identify the sources of resistance (Phenotypically / Molecular) to major insect pests/diseases (Donors / Wild relatives) duly taking into consideration the changed climate scenario.

15. AI-based crop pest / disease detection system using a different convolution neural network (DCNN) to develop decision support system need to be explored, especially using POS data.

16. Identification of new and stable multiple resistance lines / genotypes against biotic stresses (BPH, WBPH, Stem borer, gall midge, Blast, BLB and Brown spot) and study on insect-pests and diseases dynamics in different cultivation systems like direct (wet and dry) seeded rice, dry converted to wet etc.

OBITUARY

Dr. Ravi Pratap Singh

1 February 1956 – 4 November 2020

Dr. Ravi Pratap Singh started his career at Banaras Hindu University (BHU), Varanasi in 1985 as Lecturer/ Assistant Professor and promoted as Professor in 1998. He served as Professor & Head, Department of Genetics and Plant Breeding for two tenures. He served BHU for more than 30 years.

He handled a number of responsibilities and posts in administration like Chairman, Board of Studies; Dean of faculty; Member, Academic Council etc. He participated in panel discussions as an expert and visited Nepal, Bhutan and Bangladesh during 2012 and 2013. He also presented papers and chaired sessions in International symposia held at Japan (1989), USA-Mexico (2014) and Malaysia (2015).

He was associated with All India Coordinated Rice Improvement Project (AICRIP-ICAR) for more than 19 years (2001 to 2020). During his association with AICRIP as Rice Breeder, he developed five rice varieties *viz*., HUR-105, HUR 4-3, HUR-917, HUR-1304, which were released by SVRC and one HUBR 10-9 under Basmati group was released by CVRC.

He published 124 research papers, 15 book chapters and was chief editor for two journals. He was also the Zonal Councillor for North India for Society for Advancement of Rice Research (SARR).

SARR pays its respects and deep sense of gratitude to the departed soul and prays the almighty that his soul rests in peace. We also convey our deep condolences to the bereaved family.

JRR Best Paper Award

Guidelines for 2022

Purpose

The purpose of the Best Paper Award is to recognize and promote quality contributions to the Journal of Rice Research (JRR) and encourage young scientists, scholars and students who publish papers.

Eligibility

All the authors of one Research article or Review article or Short Communication published in the JRR during June and December of every year (as a regular or special issue submission) are eligible for this award. There are no limits in the number of authors involved.

Criteria

The best paper will be selected by a committee (Outside experts & Editorial Board members). Special attention will be given to the originality and novelty of the paper content, and to its utility. Additional criteria will be fixed by the committee. Award will start from June 2022 issue onwards.

How to Apply

All the published papers are automatically included in the list of papers for evaluation. No action is required.

Award

The "JRR Best paper award" includes:

- A certificate
- A Memento and
- A Cash prize

Special Thanks to Dr. Gururaj Katti, Retd. Principal Scientist & Head, Entomology section, ICAR-IIRR for reviewing and editing the manuscripts of the Journal

Journal of Rice Research - Authors Guidelines

Scope: Journal of Rice Research is a channel for publication of full length papers covering results of original research, invited critical reviews or interpretative articles related to all areas of rice science, rice based crop systems and rice crop management. The journal also publishes short communications, book reviews and letters to the editor.

Articles reporting experimentation or research in any field involving rice or rice based cropping systems will be accepted as original articles while critical reviews are generally invited. Short articles concerned with experimental techniques or observation of unique nature will be accepted as short communication. Letters to the editor concerning previous articles are welcome and are published subject to review and approval by the editorial board. The original authors will be invited to reply to the points raised in these letters for their response which are also published together.

General Requirement:

Submission to the journal must be reports of original research of at least two crop seasons and must not be previously published or simultaneously submitted to any other scientific or technical journal. At least one of the authors (in case of joint authorship) should be member of the Society for Advancement of Rice Research (SARR) and not in arrears of subscription. Authors of invited articles are exempted from this.

Submission of Manuscript:

Manuscripts should be sent by email to the chief editor (jrrchiefeditor@gmail.com/chintalapatipadmavathi68@gmail.com) as an attachment. All the enclosed figures (as ppt/jpg files), graphs (as MS Excel worksheet with original data) and photographs (as jpg or ppt files with high resolution) may be submitted as separate files. Avoid using more than one font. The manuscript should be typed in double spaced times new roman font with margins of at least 2.5 cm. On the first page give the title, a byline with the names of authors, their affiliation and corresponding author's e-mail ID. Abstract should be followed by a list of key words. The usual order of sections to be included after title and abstract pages are: Introduction which includes literature review; materials and methods; results and discussion; conclusion (optional), acknowledgements and references followed by figures and tables.

Title should give a clear idea what the articles is about. It should be brief and informative (12-15 words).

Materials and Methods should include experimental design, treatment details, replications and techniques/ methods employed.

Results and Discussion should be supported by sound scientifically analysed data along with explanatory text with relevant tables and figures.

References should be quoted in author-year notation system only. All the references should be arranged alphabetically by author. All single author entries precede multiple author entries for the same first authors. Use chronological order within entries with identical authorship and add a low case letter a, b, c, etc., to year for same year entries of the same author. References should be presented in the format given below:

Research papers

1. Durvasula V. Seshu**.** 2017. Networking a Pivotal Strategy for Rice Genetic Improvement. *Journal of Rice Research*, 10(1): 1-8.
2. Kemparaju KB, MS Ramesha, K Sruti, AS Hari Prasad, RM Sundaram, P Senguttuvel and P Revathi**.** 2018. Breeding strategy for improvement of rice maintainer lines through composite population for short term diversity. *Journal of Rice Research*, 11(2): 27-30
3. Paul M and Keegstra K. 2008. Cell-wall carbohydrates and their modification as a resource for biofuels. *Plant Journal,* 54: 559-568.

Thesis

Bhuiyan MDAR. 2010. Phenotypic and genotypic evaluation of selected transgressive variants derived from *Oryza rufipogon* Griff. x *Oryza sativa* L. cv. MR219. Ph D. Thesis. University Kebaangsaan Malaysia, Malaysia, 150 p.

Book chapter

Scott JM 1984. Catabolism of folates. P. 307-327. In R.L. Blackley and S.J. Benkovic (ed.) Folates and Pterims Vol.1. John Wiley & Sons, New York

Book

Subba Rao LV, Shobha Rani N, Chiranjeevi M, Chaitanya U, Sudharshan I, Suneetha K, Jyothi Badri and Dipal R Choudhary 2013 DUS Characterization of Rice Varieties. Directorate of Rice Research, Rajendranagar, Hyderabad-500 030, AP, India. 524 pp

Figures: Photographs and drawings for graphs and charts should be prepared with good contrast of dark and light. Figure caption should be brief specifying the crop or soil, major variables presented and year. Give careful attention to the width of lines and size, and clarity of type and symbols.

Tables: Tables are used for reporting extensive numerical data in an organized manner and statistically analyzed. They should be self explanatory. Prepare tables with the word-processing tables feature and tabs or graphics boxes should not be used. Table head should be brief but complete and self contained. Define all variables and spell out all the abbreviations. An exponential expression (eg. x 10^3) in the unit's line is often needed to keep length of the data reasonably short, and referenced with an explanatory note. Unless otherwise required, two decimal place values are suggested.

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