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Development of Hybrids with Promising Restorers under Test Cross Nursery Study in Rice (*Oryza Sativa* L.)

P. Madhukar [a*], B. Srinivas [a], P. Gonya Nayak [a] and B. Laxmi Prasanna [b]

[a] *Regional Agricultural Research Station (RARS), Polasa-505529, Jagtial Dist. Telangana State, India.*
[b] *Institute of Biotechnology (IBT), Rajendranagar, Prof. Jayashankar Telangana State Agricultural University (PJTSAU), Hyderabad-30, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The experiment was carried out during *Rabi*, 2018-19 and thirty-four rice stable lines crossed with five (5) wild abortive cytoplasmic male sterile (CMS) line to develop 170 F_1s. Those 170 F_1s were evaluated in test cross nursery evaluation (TCN) during *Kharif*, 2019 along with two locally popular checks Jagtiala Rice-1 (JGL 24423) and Bathukamma (JGL 18047). Among those 170 F_1s, 32 restorer cross combinations, 23 maintainer cross combinations and remaining 114 partial cross combinations (partial restorers or partial maintainers) were identified based on pollen fertility (%) and spikelet fertility (%). In restorer cross combinations, four stable lines *viz.*, JGL 36147, JGL 37228, JGL 36181 and JGL 37207 having spikelet fertility %, Pollen fertility% (90.5%,89.7%),

*Corresponding author: E-mail: madhu0743@gmail.com;

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(90.5%, 93%), (95%, 85%) and (90.6%, 89%) recorded respectively. In maintainer cross combinations, three stable lines JGL 36181, VT-101 and VT-106 recorded 0 to 1 % spikelet and pollen fertility percentage. Among the 32 restorer cross combinations, best 14 cross combinations (based on yield and its attributing characters) were promoted to preliminary yield trial (PHT) and evaluated in *Kharif*, 2020. Among the 14 hybrids, two hybrids namely, JGLH 447 (5.9 t/ha, 16.5%) and JGLH 442 (5.3 t/ha, 14.6%) recorded significant higher yields and low percent of gall midge incidence over locally cultivated cultivars, JGL 24423 (4.4 t/ha, 16.8%), US 312 (4.3 t/ha, 36.2%), 27P31 (4.2 t/ha, 35.6%) and HRI 174 (3.2 t/ha, 37.1%).

Keywords: Rice; restorers; pollen fertility; spikelet fertility; wild-abortive CMS.

1. INTRODUCTION

Among the cereals, rice is one of the sources of livelihood for millions of populations in India. Rice crop occupied 22% (43.5 mha) of cropped area, 129.47 million tonnes production, 3.0 t/ha productivity during 2021-22 [1] and that holds key for 43% food security in India. At present India population 1.36 billion and self-sufficient crop production available, but in next decade India population may increase 1.48 billion (2030), 1.62 billion (2050), in that situation it is need to increase rice crop productivity to self-sufficient. To meet the demands of increasing population and maintain this self-sufficiency, the present production level of around 129.4 million tons, needs to be increased up to 168 million tons by the year 2050. Hybrid rice is one of the practically feasible and readily adoptable technologies to increase production and productivity of rice in India. In rice availability of stable wild abortive cytoplasmic male sterile lines and restorers' lines, make is to breakthrough in exploitation of heterosis in rice [2,3] with three-line hybrid system. Till now nearly 1310 rice varieties and 137 rice hybrids released through SVRC and CVRC under public and private organizations in India. In rice production point of view still need to improve the good quality, high head rice recovery, high productivity pipeline cultures development necessary. In that connection development of rice hybrid through identification of promising restorer with good combinability needful to increase the rice productivity. Currently, varietal identification based on morphological traits are considered as the most widely used for certain germplasm and genotype management applications [4]. As a result, morphological characterization of new hybrid rice parental lines (A x R) and (A x B) for their production potential is important in order to increase seed yield and hybrid seed production.

In the above view, here we studied the identification of promising restorer through test cross nursery and develop the high yielding, short duration and good quality rice hybrid.

2. MATERIALS AND METHODS

The experiment was conducted at regional agricultural research station (RARS), Polasa, Jagtial district, Telangana state during *Rabi,* 2018-19 to *Kharif,* 2020. Thirty-four stable lines from source nursery were crossed with five wild abortive cytoplasmic male sterile (CMS) lines adopting clipping method during *Rabi* 2018-19. Crosses were made between single plants of the CMS lines and single plants of the stable lines at flowering to generated 170 test cross hybrids [5]. The specific male parent used for the crossing was tagged and seeds collected for inclusion in the testcross evaluation nursery. 170 testcross F_1 seeds were planted in two rows with single seedling per hill and a spacing of 15 cm × 15 cm. during *Kharif,* 2019. Eight hills of the pollen parent were planted beside the testcross F_1s in two rows to enable comparison of seed set. Two released varieties *viz.,* Jagtiala Rice-1 (JGL 24423) and Bathukamma (JGL 18047) were also included as checks to identify hybrids, which were higher yielding than the checks. Pollen and spikelet fertility were the main criteria for the evaluation of F_1 plants. Fertility and sterility were recorded according to [6]. Mature anthers were harvested and their pollen stained with 1% iodine potassium iodide solution [6]. The numbers of dark blue (stainable) and clear pollen grains (non-stainable) in each sample were recorded under an optical simple microscope. Percent pollen fertility was estimated on the basis of the number of stainable (fertile) and non-stainable (sterile) pollen [6]. Spikelet fertility was also recorded following [6]. Agronomic traits were assessed in the fertile and sterile offspring (Table 2). whereas, complete sterile F_1 hybrids were used for backcrossing to the recurrent parent to develop new CMS lines. The maintaining and restoring status of the materials was classified according to [6].

Table 1. Classification of inbred lines into restorers and maintainer (SES, IRRI, 2013)

Pollen fertility (%)	Category	Spikelet fertility (%)
0-1	Maintainers	0
1.1-50	Partial maintainers	0.1-50
50.1-80	Partial restorers	50.1-75
>80	Restorers	>75

Potential Restorers were identified as having >85% pollen fertility and >75% spikelet fertility.

The pollen fertility was calculated as follows:

$$Pollen\ fertility\ (\%) = \frac{Number\ of\ (stained\ spherical)\ pollen}{Total\ number\ of\ pollens\ counted} \times 100$$

Mature anthers were harvested and their pollen stained with 1% iodine potassium iodide solution [6]. The numbers of dark blue (stainable) and clear pollen grains (non-stainable) in each sample were recorded (Randomly 8 to 10 counts) under an optical simple microscope. Percent pollen fertility was estimated on the basis of the number of stainable (fertile), non-stainable (sterile) pollen and total number of pollens counted.

The pollen fertility was calculated as follows:

Studied for spikelet fertility per cent by bagging the primary panicles at booting to heading stage before anthesis. On the basis of spikelet fertility, pollen parents were classified as effective restorer (>80% spikelet fertility), partial restorers (20 to 80% fertility), partial maintainers (5 to 20% fertility) and effective maintainers (<1% fertility). The proportion of number of fully developed grains to the total number of spikelets was calculated as spikelet fertility.

$$Spikelet\ fertility\ (\%) = \frac{Number\ of\ filled\ grains\ per\ panicle}{Total\ number\ of\ spikelets\ per\ panicle} \times 100$$

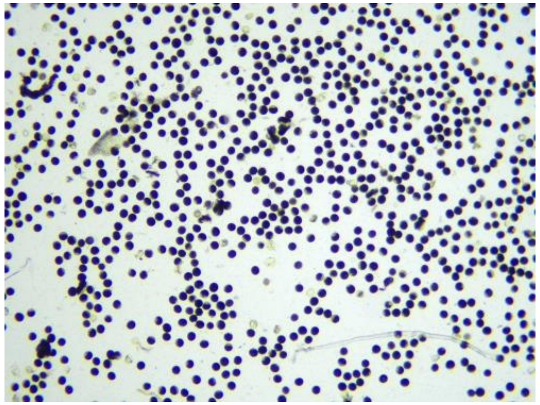
After identification of best restorer cross combination hybrids in test cross nursery (TCN), promoted to preliminary evaluation trial (PHT) trial during *Kharif,* 2020 further evaluation along with three hybrid checks like, US 312, 27P31, HRI 174 and one varietal check Jagtiala Rice-1 (JGL 24423) to identify the best hybrids over popularly cultivated high yielder varieties and hybrids. In this preliminary evaluation trial best restorer crosses were planted in 15 x15cm spacing with 6.75m^2 plot size and recorded data on days to 50% flowering, effective bearing tellers per m^2, plant height (cm), panicle length (cm), 1000 grain weight (g), spikelet fertility (%), per cent of gall midge incidence and seed yield per plot (plot size 6.75m^2).

3. RESULTS AND DISCUSSION

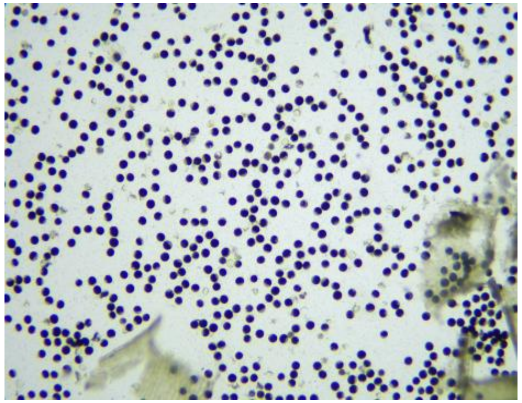
The maintainers and restorers identified in this study were represented in the Table 2. In this experiment, maintainers, partial restorers and restorers were classified based on the spikelet fertility (%), and pollen fertility (%) along with agronomical morphological data [7]. In this study, among the 170 test crosses, 32 cross combination restorers, 24 cross combination maintainers and remaining 114 cross combination partials (partial restorers or partial maintainers) were identified (Table 2) [8]. This study revealed that, among the 170 F_1s, the pollen fertility ranged from 0 to 99.1 and spikelet fertility ranged from 0 to 97.7. Among the 32 restorers, only 14 restorers behaved as a restores for more than one CMS lines, remaining 18 restorers behaved as a restorer for one CMS line and as a partial restorer for the other CMS line [8]. This kind of different reaction of the same genotype in restoring the fertility of different CMS lines of same cytoplasmic source was reported by [8,9,10]. This could be due to differential nuclear cytoplasmic interactions between the testers and CMS lines. For test cross nursery (TCN) to develop the 170 F1's, here we used 34 stable lines, among those nine best restorers identified *viz.,* JGL 36172, JGL 36181, JGL 37201, JGL 37228, JGL 36147, JGL 36199, JGL 37207, JGL 36199, VT 103 and seven best maintainers *viz.,* JGL 36141, JGL 36188, JGL 36191, JGL 37204, VT-101, VT-106, VT-107 were identified (Table 3). In restorer lines, four stable lines *viz.,* JGL 36147, JGL 37228, JGL 36181 and JGL 37207 having spikelet fertility %, pollen fertility % (90.5%,89.7%), (90.5%, 93%), (95%, 85%) and (90.6%, 89%) respectively. The results of the present study are in concurrent with those reported by [11] and [12]. The remaining stable lines *viz.,* JGL 36145, JGL 36148, JGL 36172, JGL 36175, JGL 36200, JGL 37201, JGL 37204, JGL 37250, JGL 36168, JGL 36170, JGL 36174, JGL 36199, JGL 37202, VT-102, VT-103 and VT-104 recorded more than 85% spikelet fertility and pollen fertility with one CMS line (Table 2). [9,13,14] reported three potential maintainers and two were restorers in their study and [15,16] reported potential restorers with two CMS lines.

1. Plates:

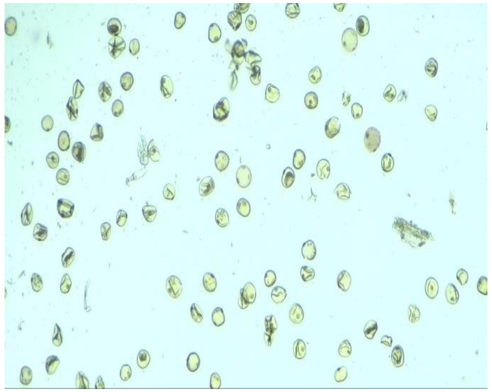
Matured anther for pollen collection



JMS 13A x JGL 37204 (Restorer -pollen parent)
Stained pollen grains (fertile)



JMS 19A x JGL 36172 (Restorer- pollen parent)
Stained pollen grains (fertile)



JMS 13A x VT 101 (Maintainer -pollen parent)
Un-stained pollen grains (sterile)

Table 2. Study of test cross nursery (TCN), *Kharif* - 2019

TCN Number	Crosses	Spikelet fertility%	Pollen fertlity %	Grain type	M/R reaction	Days to 50% flowering	Effective Bearing Tillers	Plant Height (cm)	Panicle length (cm)
TCN 3882	JMS 13A x JGL 36141	0	0	MS	B	85	20	100	32
TCN 3883	JMS 19A x JGL 36141	2.6	1.6	MS	PR	77	13	82.5	35
TCN 3884	CMS 11A x JGL 36141	7.3	9.3	LS	PR	73	16	82	22
TCN 3885	CMS 59A x JGL 36141	82.5	22.5	LS	PR	81	12	97	25.5
TCN 3886	CMS 64A x JGL 36141	0.4	2.3	LS	B	84	12	99	27.5
TCN 3887	JMS 13A x JGL 36145	**97.7**	**87.7**	**SB**	**R**	**85**	**11**	**102**	**26**
TCN 3888	JMS 19A x JGL 36145	12.8	10.8	SB	PR	79	20	85	25.5
TCN 3890	CMS 11A x JGL 36145	48.4	38.4	MB	PR	77	14	78	22.5
TCN 3893	CMS 59A x JGL 36145	68	40	MS	PR	77	12	96	26.5
TCN 3894	CMS 64A x JGL 36145	22.9	12.9	MS	PR	77	10	96.5	26.5
TCN 3895	JMS 13A x JGL 36147	75.7	70.7	MS-MB	PR	86	11	108	29.5
TCN 3896	JMS 19A x JGL 36147	**91.9**	**89.7**	**MS**	**R**	**71**	**12**	**108.5**	**30.5**
TCN 3898	CMS 11A x JGL 36147	80	51.1	MS	**PR**	78	8	95	26.5
TCN 3899	CMS 59A x JGL 36147	90.5	69	LS	**R**	79	17	109.5	25
TCN 3900	CMS 64A x JGL 36147	50	81.4	MS	PR	81	19	103	27.5
TCN 3905	JMS 13A x JGL 36159	0.5	0.1	MS	B	85	13	98.5	28
TCN 3907	JMS 19A x JGL 36159	40-50	44.2	MS	PR	85	11	90	27.5
TCN 3909	CMS 11A x JGL 36159	50	61.01	MS	PR	81	12	84	26.5
TCN 3911	CMS 59A x JGL 36159	17	5.7	SB	PR	76	12	94	26.5
TCN 3912	CMS 64A x JGL 36159	28	63.6	LS	PR	84	11	97.5	29.5
TCN 3916	JMS 19A x JGL 36168	90	49.2	SB-MB	**R**	74	12	116.5	30
TCN 3917	JMS 13A x JGL 36168	90.6	56.7	MS	**R**	76	12	100.5	25
TCN 3918	CMS 11A x JGL 36168	15	40.9	MB	PR	82	15	101.5	28.5
TCN 3919	CMS 64A x JGL 36168	20	41.17	MB	PR	82	11	107.5	27.5
TCN 3920	CMS 59A x JGL 36168	25	69	LS	PR	89	13	114.5	30
TCN 3924	JMS 19A x JGL 36170	**92.5**	**85**	**SS-MS**	**R**	**90**	**10**	**111**	**27.5**
TCN 3925	CMS 11Ax JGL 36170	15	65	MB	PR	91	6	104	27.5
TCN 3926	CMS 59A x JGL 36170	15	52	MS-MB	PR	95	22	126.5	29.5
TCN 3927	CMS 64A x JGL 36170	20	71	LS	PR	102	8	117.5	27
TCN 3921	JMS 13A x JGL 36170	10	52	MS	PR	96	13	107	28
TCN 3928	JMS 13A x JGL 36172	91.9	82	SS-MS	**R**	98	8	117	26

TCN Number	Crosses	Spikelet fertility%	Pollen fertlity %	Grain type	M/R reaction	Days to 50% flowering	Effective Bearing Tillers	Plant Height (cm)	Panicle length (cm)
TCN 3929	JMS 19A x JGL 36172	**92.5**	**86**	**MS**	**R**	**95**	**10**	**113.5**	**27**
TCN 3930	CMS 59A x JGL 36172	60	63	MS	PR	91	9	115.5	28.5
TCN 3931	CMS 64A x JGL 36172	80	72	MS	**PR**	91	9	116.5	25
TCN 3922	CMS 11A x JGL 36172	10	23	MS	PR	95	11	110	29
TCN 3932	JMS 13A x JGL 36174	5.1	15	MS	PR	90	9	114.5	28
TCN 3933	JMS 19A x JGL 36174	95.5	68	SS-MS	**R**	88	9	105	25
TCN 3934	CMS 11Ax JGL 36174	85	56.5	LS	**PR**	86	8	101	27.5
TCN 3935	CMS 64A x JGL 36174	0-2	2.6	LS	B	95	11	106.5	29.5
TCN 3937	CMS 59A x JGL 36174	5.2	10.2	LS	PR	90	11	114.5	27.5
TCN 3938	JMS 13A x JGL 36175	90.8	78	LS	R	96	12	113.5	29
TCN 3939	JMS 19A x JGL 36175	50	69	MS	PR	96	9	96.5	25
TCN 3940	CMS 11Ax JGL 36175	70	50.4	LS	PR	84	12	99.5	27.5
TCN 3941	CMS 64A x JGL 36175	56	53	LS	PR	90	11	111.5	32
TCN 3942	CMS 59A x JGL 36175	85.6	72	LS	PR	91	12	115.5	33
TCN 3943	JMS 13A x JGL 36181	90	82.5	MS	R	93	18	110	29
TCN 3944	JMS 19A x JGL 36181	85	0.03	MS-MB	PR	85	11	109	27
TCN 3945	CMS 11Ax JGL 36181	60	86.5	LS	PR	83	11	101	26.5
TCN 3947	CMS 64A x JGL 36181	**95**	**85.43**	**LS**	**R**	**79**	**10**	**99.5**	**25.5**
TCN 3948	CMS 59A x JGL 36181	60	56.8	LS	PR	85	11	108	27
TCN 3949	CMS 11Ax JGL 36182	85	99.1	LS	PR	82	12	97	27
TCN 3950	JMS 19A x JGL 36182	50	1.9	LS	PR	85	14	102.5	26
TCN 3951	JMS 13A x JGL 36182	60	45.6	LS-LB	PR	81	13	98.5	24.5
TCN 3952	CMS 59A x JGL 36182	70	47.2	LB	PR	85	12	112	26.5
TCN 3953	CMS 64A x JGL 36182	60	58.3	LS	PR	83	11	106.5	26.5
TCN 3954	JMS 19A x JGL 36188	0.2	1.2	MS	B	85	10	100	25.5
TCN 3955	CMS 11Ax JGL 36188	4.8	0.6	LS	B	74	13	87	19.5
TCN 3956	CMS 14A x JGL 36188	5	12	LS	PR	84	11	108	23.5
TCN 3957	CMS 64A x JGL 36188	50	16	MS-LS	PR	85	8	111	28.5
TCN 3973	JMS 13Ax JGL 36188	0.5	0.9	MB-LS	B	85	11	99.5	27.5
TCN 3958	CMS 11Ax JGL 36189	85	68	MS	PR	80	11	100	27.5
TCN 3959	JMS 13Ax JGL 36189	0.1	0.3	LS	B	89	10	113.5	26.5
TCN 3960	CMS 59A x JGL 36189	50	45	LS-MS	PR	84	10	116.5	29.5
TCN 3961	CMS 64A x JGL 36189	65	59	SB	PR	89	10	111.5	26.5

TCN Number	Crosses	Spikelet fertility%	Pollen fertlity %	Grain type	M/R reaction	Days to 50% flowering	Effective Bearing Tillers	Plant Height (cm)	Panicle length (cm)
TCN 3897	JMS 19A x JGL 36189	80	62.8	MS	PR	74	15	101.5	24.5
TCN 3962	JMS 19A x JGL 36191	50	53	MS	PR	96	10	117	28.5
TCN 3963	CMS 11Ax JGL 36191	0	0.2	MS	B	79	16	82.5	25.5
TCN 3964	CMS 59A x JGL 36191	40	42	LS	PR	89	9	117.5	26.5
TCN 3965	CMS 64A x JGL 36191	50	55	LS	PR	92	9	116	32
TCN 3973	JMS 13A x JGL 36191	0.5	0.6	MB-LS	B	85	11	99.5	27.5
TCN 3966	JMS 13A x JGL 36192	15	26	MS	PR	97	10	110	30
TCN 3967	JMS 19A x JGL 36192	40	46	MB	PR	90	13	115	28.5
TCN 3968	CMS 59A x JGL 36192	30	35	MS	PR	84	11	105	26.5
TCN 3969	CMS 64A x JGL 36192	0	0.3	LS	B	82	11	100	28.5
TCN 4120	CMS 11A x JGL 36192	50	65	MS	PR	93	13	108.5	28.5
TCN 3971	JMS 19A x JGL 36195	40	59	MS	PR	81	12	100.5	23.5
TCN 3972	CMS 11Ax JGL 36195	50	56	MS	PR	74	15	82.5	20.5
TCN 3974	JMS 13A x JGL 36195	9.6	12	MB	PR	71	12	89.5	23
TCN 3975	CMS 59A x JGL 36195	9.4	16	MS	PR	82	13	93.5	26.5
TCN 3976	CMS 64A x JGL 36195	0.1	0.5	LS	B	86	12	101	29.5
TCN 3977	JMS 19A x JGL 36199	**90**	**85**	**LS**	**R**	**74**	**14**	**103.5**	**28**
TCN 3978	CMS 11Ax JGL 36199	90	86	LS	R	73	12	111	22.5
TCN 3979	CMS 64A x JGL 36199	90	79	LS	R	81	8	116	25.5
TCN 3980	JMS 13A x JGL 36199	70	81	LS	PR	73	10	96.5	28.5
TCN 3981	CMS 59A x JGL 36199	**90**	**89**	**LS**	**R**	**74**	**9**	**112**	**25.5**
TCN 3982	JMS 13A x JGL 36200	90	86	MS-LS	R	80	9	112	25
TCN 3983	JMS 19A x JGL 36200	80	76	MB	PR	83	9	117	28.5
TCN 3984	CMS 11Ax JGL 36200	20	42	LS	PR	81	13	96.5	23.5
TCN 3987	CMS 59A x JGL 36200	30	38	LS	PR	84	13	109.5	27.5
TCN 3988	CMS 64A x JGL 36200	40	36	LS	PR	81	14	112	28
TCN 3989	CMS 11Ax VT 101	10	8	MB	PR	87	12	116.5	29
TCN 3990	CMS 64A x VT 101	4.5	1.6	LS	B	90	9	111.5	29.5
TCN 3991	JMS 13A x VT 101	0.2	0.5	MB	B	81	11	112	28
TCN 3992	CMS 59A x VT 101	0.2	0.6	MS	B	89	12	121	26.5
TCN 4121	JMS 19Ax VT 101	0.5	1	MS	B	96	13	121	27
TCN 3993	JMS 19A x VT 102	**90**	**88**	**MS**	**R**	**88**	**10**	**108**	**29.5**
TCN 3994	CMS 11Ax VT 102	60	65	LS	PR	90	12	117.5	30.5

TCN Number	Crosses	Spikelet fertility%	Pollen fertlity %	Grain type	M/R reaction	Days to 50% flowering	Effective Bearing Tillers	Plant Height (cm)	Panicle length (cm)
TCN 3995	JMS 13A x VT 101	10	56	MS	PR	85	11	110	29
TCN 3996	CMS 59A x VT 102	5	36	MS	PR	94	17	108.5	31
TCN 4122	CMS 64A x VT 102	4.5	61	SB-MB	PR	100	14	91.5	25.7
TCN 3997	JMS 13Ax VT 103	90	88	SB-MB	R	100	16	125	26.5
TCN 3998	JMS 19A x VT 103	50	65	MS	PR	94	13	135	29.5
TCN 3999	CMS 11Ax VT 103	90	82	MS	R	93	15	127	29
TCN 4000	CMS 59A x VT 103	90	79	MS-LS	R	93	11	127.5	29.5
TCN 4002	CMS 64A x VT 103	90	81	LS	R	92	12	120	25
TCN 4003	CMS 11Ax VT 104	90	85	LS	R	80	16	106.5	26
TCN 4004	JMS 19A x VT 104	85	75	LS	PR	75	7	101	23
TCN 4005	CMS 64A x VT 104	30	70	MS	PR	81	9	114	27
TCN 4006	JMS 13A x VT 104	85	68	MS-LS	PR	75	13	103	25
TCN 4007	CMS 59A x VT 104	85	75	LS	PR	82	11	117.5	29.5
TCN 4009	CMS 11Ax VT 106	0.2	0.5	MS	B	90	11	88	24
TCN 4010	JMS 13A x VT 106	4.5	1.3	MS	B	91	9	105.5	28
TCN 4011	CMS 59A x VT 106	10	15	MS	PR	91	12	101.5	26
TCN 4012	CMS 64A x VT 106	0.2	1.3	MS	B	90	10	98.5	29
TCN 3897	JMS 19A x VT 106	80	62.8	MS	PR	74	15	101.5	24.5
TCN 4013	JMS 13A x VT 107	5	2.5	MS	PR	89	9	98	28
TCN 4014	JMS 19A x VT 107	0.1	0.5	MS	B	90	11	117.5	24
TCN 4015	CMS 11Ax VT 107	10	11	MS	PR	87	13	91.5	24.5
TCN 4016	CMS 59A x VT 107	15	24	MS	PR	63	11	107	26
TCN 4017	CMS 64A x VT 107	0.1	0.6	MS	B	74	9	113	29.5
TCN 4022	JMS 13A x JGL 37199	50	61	MS	PR	80	11	115	26
TCN 4023	JMS 19A x JGL 37199	50	75	SS	PR	61	11	113.5	26
TCN 4024	CMS 11Ax JGL 37199	85.5	81	LS	PR	76	11	101.5	23.5
TCN 4025	CMS 64A x JGL 37199	60	59	LS	PR	76	11	111.5	26.5
TCN 4026	CMS 59A x JGL 37199	20	97.3	MS	PR	74	8	109.5	26
TCN 4027	JMS 13Ax JGL 37200	60	72	MS	PR	73	11	130	30.5
TCN 4029	JMS 19A x JGL 37200	80	75	MS	PR	73	7	105.5	29.5
TCN 4032	CMS 11A x JGL 37200	70	89.3	LS	PR	80	9	111	25
TCN 4034	CMS 59A x JGL 37200	60	68	LS	PR	80	9	138.5	27
TCN 4035	CMS 64A x JGL 37200	60	68	LS	PR	91	10	113	28

TCN Number	Crosses	Spikelet fertility%	Pollen fertlity %	Grain type	M/R reaction	Days to 50% flowering	Effective Bearing Tillers	Plant Height (cm)	Panicle length (cm)
TCN 4036	JMS 13Ax JGL 37201	**90**	**88**	**MS**	**R**	**86**	**14**	**121**	**29**
TCN 4037	JMS 19A x JGL 37201	90	85	MB	R	85	9	120	27
TCN 4038	CMS 11A x JGL 37201	50	62	SS	PR	81	8	93.5	24
TCN 4039	CMS 64A x JGL 37201	70	75	LS	PR	90	11	128.5	31
TCN 4040	CMS 59A x JGL 37201	80.5	92.08	MS-LS	PR	88	10	109.5	30.5
TCN 4041	JMA 13Ax JGL 37202	70	68	MB	PR	87	12	111.5	31
TCN 4042	JMS 19A x JGL 37202	85	65	SS	PR	80	8	94	25
TCN 4043	CMS 14A x JGL 37202	4.5	35	LS	PR	89	11	107.5	27.5
TCN 4044	CMS 59A x JGL 37202	90	75	SS	R	87	17	110	29
TCN 4103	CMS 64A x JGL 37202	85	56.6	MS	PR	92	13	104	29
TCN 4045	JMS 19A x JGL 37203	50	35	SB	PR	88	10	112	26
TCN 4046	JMS 13A x JGL 37203	60	98.7	SS-MS	PR	82	9	109.5	25
TCN 4047	CMS 64A x JGL 37203	0.2	8.9	LS	B	92	11	112	30.5
TCN 4048	CMS 11A x JGL 37203	50	42	MB	PR	80	11	98.5	24.5
TCN 4049	CMS 59A x JGL 37203	60	55	LS	PR	90	12	119.5	31.5
TCN 4050	JMS 13Ax JGL 37204	**94.8**	**78**	**MS**	**R**	**90**	**10**	**116.5**	**28.5**
TCN 4051	JMS 19A x JGL 37204	80.6	74	MS	PR	81	12	110	24.5
TCN 4052	CMS 64A x JGL 37204	80	76	MB	R	80	12	104.5	23
TCN 4053	CMS 59A x JGL 37204	0.2	11	MS	B	90	13	103.5	27
TCN 4115	CMS 11Ax JGL 37204	0.5	15	MS	B	89	17	92	26.5
TCN 4054	JMS 13A x JGL 37207	80	75	MB	PR	90	9	109	28
TCN 4055	CMS 11Ax JGL 37207	80	79	SS	PR	89	10	111	27
TCN 4056	CMS 64A x JGL 37207	70	69	SS	PR	89	9	105	27.5
TCN 4058	JMS 19A x JGL 37207	90.6	86	SS-SB	R	86	9	115	28.5
TCN 4059	CMS 59A x JGL 37207	**95.5**	**89**	**LS**	**R**	**87**	**11**	**124**	**28**
TCN 4062	JMS 13Ax JGL 37209	50	65	MB	PR	91	14	108	25
TCN 4064	JMS 19A x JGL 37209	50	45	MB	PR	85	8	110	30
TCN 4065	CMS 11A x JGL 37209	50	97	SS	PR	78	9	116	21.5
TCN 4066	CMS 59A x JGL 37209	70	69	MS	PR	81	11	112.5	29.5
TCN 4067	CMS 64A x JGL 37209	15.2	26	LS	PR	88	13	116	27
TCN 4068	JMS 19A x JGL 37228	50	52	MS	PR	91	13	107.5	29
TCN 4070	CMS 64A x JGL 37228	30	16.5	LS	PR	92	23	123	30.5
TCN 4071	JMS 13Ax JGL 37228	**95**	**93**	**MS**	**R**	**91**	**10**	**113.5**	**27**

TCN Number	Crosses	Spikelet fertility%	Pollen fertlity %	Grain type	M/R reaction	Days to 50% flowering	Effective Bearing Tillers	Plant Height (cm)	Panicle length (cm)
TCN 4072	CMS 11Ax JGL 37228	70	91.5	MS	PR	90	10	121	24.5
TCN 4075	CMS 59A x JGL 37228	90.6	93.9	LS-MS	R	88	11	118.5	29
TCN 4080	JMS 13Ax JGL 37230	**95**	**85**	**MS**	**R**	**81**	**11**	**104**	**27**
TCN 4081	CMS 64A x JGL 37230	70	72	LS	PR	81	13	105	29
TCN 4082	CMS 11A x JGL 37230	50	55	SB	PR	74	9	89.5	26.5
TCN 4083	CMS 59A x JGL 37230	70	69	LS	PR	81	11	101	28
TCN 4119	JMS 13A x JGL 37230	40	39	MS	PR	88	14	109.5	31.5

R: Restorer, PR: Partials, B: Maintainers and LS: Long slender, MS: Medium slender, SS: Short slender, SB: Short bold. MB: Medium bold

Table 3. Identification of restorers and maintainers for various CMS lines

CMS Lines	Restorers	Maintainers
JMS 13A (11 restorers)	JGL 36145, JGL 36148, JGL 36172, JGL 36175, JGL 36181, JGL 36200, JGL 37201, JGL 37204, JGL 37228, JGL 37250, VT-103.	JGL 36141, JGL 36159, JGL 36188, JGL 36189, JGL 36191, VT-101, VT-106.
JMS 19A (9 restorers)	JGL 36147, JGL 36168, JGL 36170, JGL 36172, JGL 36174, JGL 36199, JGL 37201, JGL 37207, VT-102.	JGL 36188, VT-101, VT-107
CMS 11A (3 restorers)	JGL 36199, VT-103, VT-104	JGL 36188, JGL 36191, JGL 37204, VT-106.
CMS 59A (6 restorers)	JGL 36147, JGL 36199, JGL 37202, JGL 37207, JGL 37228, VT-103.	JGL 37204, VT-101.
CMS 64A (3 restorers)	JGL 36181, JGL 36199, VT-103.	JGL 36141, JGL 36174, JGL 36192, JGL 36195, JGL 37203, VT-101, VT-106, VT-107.

Table 4. Preliminary yield trial (PHT) during *Kharif,* 2020

Entry	Cross	Days to 50% flowering	Effecti ve bearin g tillers/ m2	Plant height (cm)	Panicle length (cm)	1000 grain weight (g)	Spikelet fertility %	% of gall midge incidence	Yield (kg/plot)	Yield (kg/ha)
JGLH 447	JMS 13A x JGL 37204	104	427	106.4	24.8	17.54	95.6	16.54	4.03	5972
JGLH 442	JMS 19A x JGL 36172	108	398	102.9	24.8	16.63	89.7	14.63	3.61	5353
JGLH 450	JMS 13A x JGL 37230	96	425	98.4	25.1	19.82	82.5	32.61	3.56	5271
JGLH 448	CMS 59A x JGL 37207	103	398	101.9	25.7	20.59	88.1	32.85	3.42	5065
JGLH 446	JMS 13A x JGL 37201	99	427	100.5	25.4	18.68	92.5	20.85	3.26	4827
JGLH 444	CMS 59A x JGL 36199	96	374	99.3	26.8	26.04	76.4	28.08	3.06	4535
JGL24423	Varietal Check/LC	103	389	98.7	25	26.9	83.4	16.18	3.00	4444
JGLH 449	JMS 13A x JGL 37228	100	436	98.6	22.8	18.19	80.1	33.52	2.99	4425
US 312	Hybrid check	103	422	108.5	27.2	22.05	85.5	36.22	2.92	4323
27P31	Hybrid check	105	414	105	24.6	26.3	90.8	35.61	2.83	4190
JGLH 440	JMS 19A x JGL 36147	102	396	102.9	26.4	16.5	82.8	14	2.70	3996
JGLH 451	CMS 64A x MTU 1121	106	473	97.1	25	23.27	75.2	36.97	2.54	3770
JGLH 443	CMS 23A x JGL 36181	98	411	85.2	22.2	26	75.8	30.18	2.32	3430
HRI 174	Hybrid check	106	389	103	25.1	23.06	91.2	37.13	2.14	3164
JGLH 441	JMS 19A x JGL 36170	102	396	99.8	23.8	15.31	75.8	14.1	2.07	3067
JGLH 453	CMS 14A x JGL 36199	99	376	98.2	25.6	26.68	63.0	32.53	1.96	2903
JGLH 452	JMS 13A x JGL 36145	107	429	102.6	23.7	21.6	75.0	19.68	1.29	1916
JGLH 445	JMS 19A x VT 102	102	442	104.5	25.1	16.18	74.0	15.28	1.19	1768
Means		**102**	**412**	**100.75**	**24.95**	**21.18**	**81.2**	**25.94**	**2.72**	**4023**
CV (%)		1.32	6.63	2.5	4.1	5.18	15.5	39.17		11.69
CD (5%)		2.86	N.S.	5.35	2.17	2.34	53.93	N.S.		1000.5

In this experiment total 32 cross combinations recorded restorer reaction with either one or two CMS lines cross combination. In that, only 14 cross combinations *viz.,* TCN numbers 3887,3896,3924,3929,3947,3977,3981,3993,4002,4036,4050,4059,4071 and 4080 promoted to preliminary yield trial (PHT) and study during *Kharif,* 2020 (Table 4). Remaining 18 cross combinations *viz.,* TCN numbers 3899, 3916, 3917, 3928, 3933, 3938, 3943, 3978, 3979, 3982, 3997, 3999, 4000, 4003, 4037, 4044, 4058 and 4075 were rejected even-though noticed more than 90 per cent spikelet fertility (%), but less than 85 percent pollen fertility (%). Previously, this type of results was reported by [8,12,16,17]. In this study *i.e.* the crosses like, JMS 13A x JGL 36145 (TCN 3887), JMS 19A x JGL 36147 (TCN 3896), CMS 64A x JGL 36181 (TCN 3947), JMS 19A x VT 102 (3993), JMS 13Ax JGL 37204 (4050) and JMS 13Ax JGL 37230 (4080) recorded short duration (71 to 85 days to 50% flowering), dwarf nature (99 to 108 cm.), long panicle (25.5 to 30.5 cm.). Later, in *Kharif*, 2020 fourteen (14) cross combinations evaluated in preliminary evaluation trial (PHT) trial along with three hybrid checks like, US 312, 27P31, HRI 174 and one varietal check Jagtiala Rice-1 (JGL 24423) to identify the best hybrids over popularly cultivated high yielder varieties and hybrids. Based on the earlier way of studies like, [18,19,20]. In this preliminary evaluation trial days to 50% flowering (96 to 108 days), effective bearing tellers per m^2 (374 to 473), plant height (85.2cm to 108.5cm), panicle length (22.2cm to 27.2cm), 1000 grain weight (15.31g to 26.90g), spikelet fertility (63% to 95.6%), per cent of gall midge incidence (14% to 37.13%) and seed yield per plot (1.19kg to 4.03kg) (plot size $6.75m^2$) data was recorded [21,22].

In preliminary evaluation trial (PHT) trial JGLH 447, JGLH 442, JGLH 450, JGLH 448, JGLH 448, JGLJ 446 and JGLH 444 recorded numerically superior yield (Table 4) over local varietal check JGL 24423 and hybrid checks (US 312, 27P31 and HRI 174). In this trial the entries JGLH 447, JGLH 442, JGL 24423, JGLH 440, JGLH 441 and JGLH 445 recorded low percent of gall midge incidence like, 16.54%, 14.63%, 16.18%, 14%, 14.1% and 15.28% respectively (earlier reporters viz., [17,23,21]. out of 14 entries tested along with four checks, two entries JGLH 447 (5972 kg/ha) and JGLH 442 (5353 kg/ha) recorded significant higher yields over JGL 24423 (4444 kg/ha), US 312 (4323 kg/ha), 27P31 (4190 kg/ha) and HRI 174 (3164 kg/ha) related study reported by [21,22,24].

4. CONCLUSION

34 stable lines crossed with five wild abortive cytoplasmic male sterile (CMS) line, among those eight lines like, JGL 36199, VT-103, JGL 36172, JGL 36181, JGL 37201, JGL 37228, JGL 36147 and JGL 37207 were identified as a best restorer and six maintainers like, VT-101, VT-106, VT-107, JGL 36141, JGL 36188 and JGL 36191 were identified as a best maintainer. In cross combinations the best hybrids like JGLH 447 (JMS 13A x JGL 37204) (5.9 t/ha, 16.54%) and JGLH 442 (JMS 19A x JGL 36172) (5.3t/ha, 14.63%) recorded significant higher yields and low percent of gall midge incidence over JGL 24423 (4.4t/ha, 16.18%), US 312 (4.3t/ha, 36.22%) ,27P31 (4.2t/ha, 35.61%) and HRI 174 (3.2t/ha, 37.13%) similar hybrid evaluation studies recorded by [25,26,27,28].

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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