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Evaluation of cytoplasmic male sterile lines for yield, stigma receptivity and influence of floral traits on the outcrossing rate in rice (*Oryza sativa* L.)

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ABSTRACT

Eleven cytoplasmic male sterile (CMS) lines and their respective maintainer lines were evaluated during kharif,2017 for morphological and floral traits to identify CMS lines with better outcrossing potential and yield. Attempt was also made to study the association among the traits in order to select phenotypes with desirable trait combinations.The data revealed that stigma receptivity has decreased day by day after openingof florets in all the genotypes though the percentage vary from one to other. The maximum stigma receptivity percentage was recorded in CMS 23A (71%) followed by JMS 17(55.8%), CMS 46A(48.6%), CMS 11A(48%), JMS 18A(45.4%), however these lines had lower outcrossing potential which might be due to lower angle of glume opening and stigma exertion. The range of duration and angle of glume opening was from 42.7 minute. to 171.3minute. and 17.7^o to 30.3^o, respectively. Pollen and spikelet fertility data revealed that all the CMS lines studied exceptJMS 14A were found to be good without sterility break down.The outcrossing ratewas positively correlated with the glume opening angle. Stigma receptivity had positive significant correlation with soluble sugar content in florets. Among the tested lines, CMS 59A has been found superior for both outcrossing potential and yield, CMS 46A and CMS 64A were found superior for outcrossing potential.

***Keywords*:** CMS lines, outcrossing, rice, stigma exertion, stigma receptivity.

In the world, around 117 countries grow rice (*Oryza sativa* L.), hence called as "global grain"(Farooq *et al.*, 2019). Rice has been staple food for more than half of the world's population. India witnessed an impressive growth in rice production in the post-independence era due to the adoption of semi dwarf high yielding varieties coupled with the adoption of intensive input based management practices. Rice production has increased by four times, productivity by three times while the area was almost unchanged since 2000. In order to keep pace with the growing population, the estimated rice requirement by 2025 is about 140 mt (Anup Das *et al.*). Most of the area in India has been covered by cultivation of pure line varieties owing to the ease in the availability of seed and reuse of own seed grown in their farm thus reduces the input cost, besides having verygood cooking quality with reasonably good crop yield. However, production from the varieties cannot meet the demand of 140 mt. Cultivation of hybrids offers an alternative to increase production and productivity. The increase in yield in hybrid rice is about 15-30% than the existing high yielding varieties (Haque *et al*., 2015). Total 15 million ha (50%) of the rice area in China has been planted with inbred varieties producing 81 million tons (an average yield of 5.4 t ha^{-1}) whereas, remaining 15 million ha is with hybrid varieties producing 103.5 million tons of paddy annually (an average yield of 6.9 t ha^{-1}) which was 27% (1.5 t.ha^{-1}) more than the inbred varieties (Tanweer and Abrar, 2018). The area under rice in India was 43.79 m ha (Agricoop, 2018[b]) with production of 115.6 m tons (Agricoop, 2018[a]). During the year, 2019, hybrid rice was planted in an area of 3 m ha and more than 80% of the total hybrid rice area is in the states of Uttar Pradesh, Jharkhand, Chhattisgarh, Madhya Pradesh, Odisha and Haryana. (Anonymous, 2020). Commercial exploitation of heterosis has been made possible by the use of cytoplasmic genetic male sterility (CGMS) and fertility restoration system *i.e* three-line system of hybrid rice production. Three lines were involved in the CGMS system namely a cytoplasmic male sterile (CMS) line, a maintainer line and a restorer line where the maintainer line maintains the male sterility of CMS line and restorer line (R line) possesses dominant fertility restoring genes to restore fertility in the derived F_1 hybrid.

Rice was self-pollinated crop, although outcrossing rate ranged from 0 to 44% has been reported in male sterile lines (Veeresha *et al.*, 2013). In hybrid rice breeding more than 90 per cent of the hybrids released throughout the world are based on a single male sterile cytoplasm *viz*., wild abortive (WA) and more over limited to very few lines in commercial production, which underscores the need for diversification of male sterile lines. Higher outcrossing rate is the important parameter of

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female lines for good hybrid seed yields. Though many of the heterotic hybrids have been identified, majority of them failed in commercial scale due to poor hybrid seed production yields. The application of gibberellic acid (GA_3) increased *per cent* seed set from 38.3% to 48.0% in hybrid rice due to increase in the number of filled grains per panicle (Thoithoi *et al.,* 2014), but the application of gibberellic acid raises the total expenditure on seed production by about Rs.8000-9000/- per hectare.The extent of out crossing on male sterile lines was influenced by its morphological and floral traits *viz.* Plant height, panicle length, panicle exertion (%), stigma exertion (%), stigma receptivity, duration of glume opening and the glume opening angle etc. (Manonmani *et al.,* 2012). Though the outcrossing rate of CMS line plays a critical role in making successful hybrid, as mostly hybrid rice research is being carried out by private industries and very few of the public institutes are involved and very limited research has been published in this aspect. Hence an experiment was formulated and executed to study the morphological and floral traits influencing the outcrossing rate of CMS lines in rice.

MATERIALS AND METHODS

During *kharif,* 2017 eleven CMS lines along with their maintainer lines were raised at Rice Research Center, Agricultural Research Institute, Rajendranagar, Hyderabad. The list of CMS lines and maintainer lines used in the experiment is given in Table 1.Among the CMS lines, CMS 64A was extensively used by both private and public institutions for commercial cultivation and several hybrids were developed, as it has very good outcrossing potential. Five high yielding varietal checks *viz.,*RNR 15048, JGL 18047, JGL 11470, JGL 1798 and MTU 1010 were also included in the study for comparison of yield and related traits. All the lines were grown in randomized block design with three replications by adopting a spacing of 20 cm and 15 cm between the rows and plants, respectively. All recommended package of practices were followed to raise a good crop. The observations *viz.*, days to 50% flowering, plant height (cm), panicle length (cm), panicle exertion (%), duration of the glume opening (minute), angle of glume opening (°), the length of exerted stigma (ìm), stigma exertion (%), stigma receptivity (%), pollen fertility (%), spikelet fertility (%)and soluble sugars in florets (mg. g^{-1}) were recorded in all the CMS lines. Whereas the traits *viz.*, the number of productive tillers, the number of grains per panicle, test weight (g) and grain yield (g $plant^{-1}$) were recorded on maintainer lines to measure maximum yield capability of CMS lines.Spikelet fertility (%) was also recorded in respective maintainer lines. Panicle exertion refers to the percentage of panicle that came out from the flag leaf sheath to the total length. Duration of the glume opening wasmonitored at flowering stage. Rice florets in general; bloom between 9:00 AM – 12:00 noon. Blooming and closing time of glumes was recorded on 10 blooming florets of each male sterile line and mean values were calculated. Angle of glume opening was measured on each floret using protractor. Stigma exertion percentage refers to the percentage of the stigma that came outside the glume to the total length. About 5-10 spikelets each from the freshly emerged panicles of 5 plants were collected and examined under the microscope with 1% Iodine Potassium Iodide (I-KI) for pollen sterility assessment (Virmani *et al*., 1994). Five panicles from each CMS line were covered with butter paper bags before flowering to ensure no pollination with foreign pollen and observed the spikelet fertility percentage at harvest. Anthrone method was used to estimate the total soluble sugar (Yoshida and Parao, 1972).

To record the stigma receptivity, twenty panicles were randomly selected in each CMS line. The spikelets opened in a day were observed and tagged by clipping a portion of their glume in all the twenty panicles at the peak flowering time. The tagged panicles were covered with butter paper bag and properly labeled. On every next day, four out of twenty tagged panicles were pollinated with bulk viable pollen and covered with butter paper bags. Likewise, the pollination was done for five consecutive days at four panicles on each day and labeled accordingly. These panicles were observed at 20 days after pollination and recorded the number of filled seeds against tagged (clipped) spikelets.

The stigma receptivity (%) was calculated as per formula given below.

$$\text{Stigma receptivity (\%)} = \frac{\text{No. Of filled seeds from tagged spikelets}}{\text{Total no. Of tagged spikelets}} \times 100 \quad \text{.........} (1)$$

A and B lines were planted in 4:2 ratio by adopting the row spacing of 15cm between CMS lines and 30 cm between B lines and A & B lines. The uniform intra row spacing of 15 cm was maintained with a row length of 6 m each. Supplementary pollination was done for about one week during the peak flowering stage to enable maximum out crossing. About 20 panicles were selected in each CMS line at harvest to record the outcrossing percentage as per formula given below.

$$\text{Outcrossing percentage} = \frac{\text{Number of seeds set per panicle in CMS line}}{\text{Total number of seeds per paniclein CMS line}} \times 100 \quad \text{...} (2)$$

The data was subjected to standard statistical tools and analyses of variance (Fisher, 1918) to derive valid conclusions.The methods provided by Al-Jibouri *et al.* (1958) were used to study the correlation between morphological, floral traits and outcrossing rate.

RESULTS AND DISCUSSION

The results of analysis of variance (ANOVA) for yield and yield component characters studied are presented in Table 2. Highly significant mean squares due to genotypes were observed for all traits, indicating the existence of sufficient variation among the genotypes for yield and yield component characters studied in the present investigation, and therefore, there is a scope for effective selection.

The mean values of yield and yield component traits are presented in Table 3.The data revealed that CMS 59B recorded significantly highest grain yield per plant (63.79 g) over best check, RNR 15048 (43.54 g), whereas CMS 23B recorded the lowest grain yield (24.54 g). The genotype, CMS 46B recorded the highest test weight (23.3 g) followed by CMS 59B (21.3 g), whereas JMS 17B (11.9 g) recorded the lowest test weight followed by JMS 18B (12.2 g). Bold grains confer higher test weight and hence for development of bold grain hybrids, the parents *viz.*, CMS 46A and CMS 59A could be used and likewise JMS 17A and JMS 18A for fine grain hybrids. Oladosu *et al.* (2014) reported such variation in test weight among the genotypes and observed variability was due to the genetic nature of genotypes (Hussain *et al.*, 2014).Test weight exhibited a comparatively higher estimate of phenotypic as well as genotypic coefficient of variation, this indicates that the effectiveness of simple selection for this trait (Dash *et al.*, 2011).

Days to 50% flowering were more in JMS 14B (97 days) followed by JMS 13B (96 days) and were onpar with each other. Among the genotypes, five lines *viz.*, CMS 11B, CMS 23B, JMS 11B, JMS 17B and JMS 18B were early with 85 days of flowering and hence these parents could be utilized for development of short duration hybrids.

Among yield components, productive tillers are very important because the final yield is mainly a function of the number of panicle bearing tillers per unit area (Baloch *et al.*, 2006). Among all the genotypes studied CMS 59B (15.7) and CMS 11B (15.2) have shown more number of productive tillers per plant. Similarly, CMS 59B having more number of productive tillers also had the highest grain yield per plant. Grain yield per plant has positive and significant correlation with productive tillers per plant (Sowjanya *et al.,* 2016). Panicle length determines how many spikelets would be found in a panicle and therefore filled spikelets and consequently the final grain yield. The longer the panicle, the more the spikelets and filled grains, if other environmental conditions are not limiting (Oladosu *et al.,* 2014). Panicle length was highly associated with grain yield (Chakraborty *et al.*, 2010). Among the genotypes, panicle length was maximum in JMS 13B (25.8 cm) followed by JMS 14B (25.5 cm), CMS 59B (25.2 cm) and JMS 11B (25.2 cm) and were on par with superior checks, JGL 11470 (25.2 cm) and RNR 15048 (24.8 cm). It was also clear that the genotypes showing higher panicle length also had relatively higher grain yield.

JMS 14B (283.8) was recorded maximum grain number followed by JMS 17B (281.9), JMS 13B (262.9), JMS 11B (248.3), JMS 18B (246.9) and were on par with superior checks, RNR 15048 and JGL 1798. The results clearly mention that the CMS lines developed at IRRI, Philippines had lesser grain number as compared to indigenous lines. However, the grain number and test weight combinedly influence the final grain yield.

Shiyam *et al*. (2014) observed significant differences for grain filling among hybrids and the check variety. Maximum spikelet fertility percentage of 92.8 was recorded in JMS 11B, which was significantly superior over all the genotypes and checks. High yield potential was not achieved in rice due to factors such as poor grain-filling (Ao *et al.,* 2008), slow grain-filling rate and many unfilled grains (Yang *et al.,* 2002).

Besides yield and yield contributing traits, floral traits affecting out cross rate plays pivotal role in commercial utilization of CMS lines for development of hybrids. Significant variation was observed for stigma receptivity among the CMS lines evaluated (Table 4). Data showed that at one day after flowering, CMS 23A (94%) recorded the highest stigma receptivity followed by JMS 17A (93%), CMS 11A (85%) and JMS 14A (85%). Whereas CMS 14A (43%) and JMS 13A (43%) have recorded least stigma receptivity even at one day after flowering. The data clearly revealed that stigma receptivity has decreased day by day after opening of florets in all the genotypes though the percentage vary from one to other. Genotype JMS 11A has lost stigma receptivity on 4th day after opening whereas CMS11A and CMS 46A were

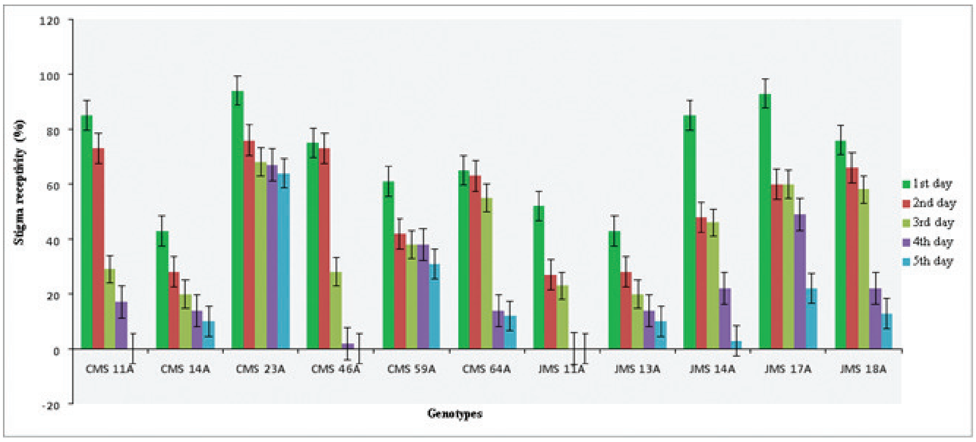

Fig. 1. Stigma receptivity (%) for five continuous days after flowering of florets in CMS lines of rice

Table 1: List of CMS lines and maintainer lines used in the experiment

CMS Lines	Maintainer Lines	Source	Character
CMS 11A	CMS 11B	IRRI, Philippines	LS grain, Very early duration
CMS 14A	CMS 14B	IRRI, Philippines	LS grain, Early duration
CMS 23A	CMS 23B	IRRI, Philippines	LB grain, Very early duration
CMS 46A	CMS 46B	IRRI, Philippines	LS grain, Early duration
CMS 59A	CMS 59B	IRRI, Philippines	LS grain, Mid early duration
CMS 64A	CMS 64B	IRRI, Philippines	LS grain, Early duration
JMS 11A	JMS 11B	RARS, Jagtial, Telangana, India	LS grain, Early duration
JMS 13A	JMS 13B	RARS, Jagtial, Telangana, India	MS grain, Medium duration
JMS 14A	JMS 14B	RARS, Jagtial, Telangana, India	MS grain, Medium duration
JMS 17A	JMS 17B	RARS, Jagtial, Telangana, India	SS grain, Mid early duration
JMS 18A	JMS 18B	RARS, Jagtial, Telangana, India	SS grain, Mid early duration
Checks			
RNR 15048		RRC, ARI, Hyderabad, Telangana, India	SS grain, Early duration
JGL 18047		RARS, Jagtial, Telangana, India	LS grain, Early duration
JGL 11470		RARS, Jagtial, Telangana, India	SS grain, Medium duration
JGL 1798		RARS, Jagtial, Telangana, India	MS grain, Early duration
MTU 1010		APRRI, Maruteru, AP, India	LS grain, Early duration

Notes:LS: Long Slender, MS: Medium Slender, SS: Short Slender, LB:Long Bold

lost stigma receptivity on 5th day after opening. The remaining genotypes have stigma receptivity even at 5th day after opening. The decrease in receptivity from 1st day to 5th day after flowering was very less in CMS 23A (31.9%) followed by CMS 59A (49.2%).

The mean data over 5 consecutive days of pollination revealed that CMS 23A had the highest stigma receptivity (71%) followed by JMS 17A (55.8%), CMS 46A (48.6%) and CMS 11A (48%) whereas CMS 14A (18.0%) recorded minimum mean stigma receptivity followed by JMS 13A (18.1%). CMS 23A was found to be superior for stigma receptivity followed by JMS 17A and CMS 59A. (Fig.1)

The mean performance of CMS lines for various other floral traits ispresented in Table 5. CMS 46A had the highest duration of glume opening (171.3 min) followed by CMS 11A (156.3 min). In contrary JMS 18A (42.7 min.) recorded lowest glume opening duration followed by JMS 17A (59.7 min.) which might result in poor outcrossing rate. Among the CMS lines, angle of the glume opening ranged from 17.7^{o} to 30.3^{o}. CMS 46A (30.3^{o}) recorded withmaximum glume angle followed by CMS 59A (30^{o}) and CMS 64A (29.3^{o}) and the least angle of glume opening was observed in JMS 18A (17.7^{o}). Manonmani *et al.* (2012) reported the range of glume opening as 20^{o} to 35^{o}. Increased spikelet opening

Table 2: ANOVA for yield and yield contributing traits in rice

Treatments	Degrees of freedom	Days to 50% flowering	Plant height (cm)	No. of productive tillers	Panicle length (cm)	No. of grains per panicle	Spikelet fertility (%)	Test weight (g)	Grain yield Plant^{-1} (g)
Replicates	2	0.33	53.49	6.96	0.16	34.62	1.49	0.65	108.14
Treatments	15	116.44**	159.48**	5.89**	6.68**	14472.2**	87.66**	60.53**	319.44*
Treatment Error	30	0.56	12.50	2.11	2.09	1155.59	1.94	1.65	47.81
Total	47	37.53	61.15	3.52	3.47	5357.87	29.28	20.40	137.07
General mean		91.52	103.12	12.53	23.83	219.11	82.98	18.17	38.61
C.V.		0.81	3.43	11.60	6.10	15.51	1.68	7.10	17.91
C.D. 95%		1.24	5.90	2.42	2.41	56.69	2.32	2.14	11.53

***, ** Significance Levels at 0.05 and 0.01, respectively**

Table 3.Mean performance of the genotypes and checks for biometrical attributes in rice

Treatments	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers	No. of grains per panicle	Spikelet fertility (%)	Test weight (g)	Grain yield . plant^{-1}(g)
CMS 11B	85.0	92.4	20.5	15.2	140.4	80.4	18.7	40.81
CMS 14B	94.0	107.2	23.3	13.6	195.0	79.1	20.1	41.38
CMS 23B	85.0	91.8	24.5	11.7	133.2	69.1	21.1	16.54
CMS 46B	89.0	98.9	23.7	11.9	148.0	81.0	23.3	44.39
CMS 59B	90.7	113.3	25.2	15.7	184.9	84.1	21.3	63.79
CMS 64B	91.0	99.7	23.3	11.1	190.9	77.3	19.6	34.97
JMS 11B	85.0	105.7	25.2	11.4	248.3	92.8	20.2	42.82
JMS 13B	96.0	112.0	25.8	11.3	262.9	85.8	17.4	35.48
JMS 14B	97.0	102.4	25.5	12.3	283.8	86.6	13.6	41.74
JMS 17B	85.0	95.1	24.0	13.8	281.9	83.1	11.9	42.22
JMS 18B	85.0	96.1	23.0	12.4	246.9	79.8	12.2	25.38
RNR 15048(C)	97.0	115.4	24.8	12.1	303.9	86.3	12.7	43.54
JGL 18047 (C)	89.0	102.4	21.5	11.8	121.8	86.1	24.7	26.70
JGL 11470 (C)	107.0	101.2	25.2	11.8	339.6	83.9	13.0	43.10
JGL 1798 (C)	97.0	108.4	22.5	11.1	276.2	83.3	15.7	38.49
MTU 1010 (C)	91.7	107.7	23.3	13.3	148.0	89.0	25.1	36.31
Mean	91.5	103.1	23.8	12.5	219.1	83.0	18.2	38.60
C.V.	**0.8**	**3.4**	**6.1**	**11.6**	**15.5**	**1.7**	**7.1**	**17.91**
C.D. 5%	**1.24**	**5.90**	**2.41**	**2.42**	**56.68**	**2.32**	**2.14**	**11.53**
S.E ±	**0.4**	**2.0**	**0.8**	**0.8**	**19.6**	**0.8**	**0.7**	**4.0**

Table 4: Stigma receptivity (%) of different CMS lines in rice.

	Treatments	Days after flowering					Average	*Per cent* Decrease in stigma receptivity from 1st to 5th day
		1st	2nd	3rd	4th	5th		
CMS11A	No. of spikelets Cut	73	75	45	100	20	313.0	
	No. of spikelets Set seed	62	55	13	17	0	147.0	
	Stigma receptivity (%)	**85**	**73**	**29**	**17**	**0**	**48.0**	**100.0**
CMS14A	No. of spikelets Cut	23	36	87	76	93	315.0	
	No. of spikelets Set seed	10	10	17	11	9	57.0	
	Stigma receptivity (%)	**43**	**28**	**20**	**14**	**10**	**18.0**	**76.7**
CMS23A	No. of spikelets Cut	71	143	213	167	177	771.0	
	No. of spikelets Set seed	67	109	144	112	113	545.0	
	Stigma receptivity (%)	**94**	**76**	**68**	**67**	**64**	**71.0**	**31.9**
CMS46A	No. of spikelets Cut	118	158	114	53	47	490.0	
	No. of spikelets Set seed	89	116	32	1	0	238.0	
	Stigma receptivity (%)	**75**	**73**	**28**	**2**	**0**	**48.6**	**100.0**
CMS59A	No. of spikelets Cut	97	92	109	124	127	549.0	
	No. of spikelets Set seed	59	39	41	47	40	226.0	
	Stigma receptivity (%)	**61**	**42**	**38**	**38**	**31**	**41.2**	**49.2**
CMS64A	No. of spikelets Cut	62	82	44	84	114	386.0	
	No. of spikelets Set seed	40	52	24	12	14	142.0	
	Stigma receptivity (%)	**65**	**63**	**55**	**14**	**12**	**36.8**	**81.5**
JMS 11A	No. of spikelets Cut	63	102	61	46	54	326.0	
	No. of spikelets Set seed	33	28	14	0	0	75.0	
	Stigma receptivity (%)	**52**	**27**	**23**	**0**	**0**	**23.0**	**100.0**
JMS 13A	No. of spikelets Cut	23	36	87	76	93	315.0	
	No. of spikelets Set seed	10	10	17	11	9	57.0	
	Stigma receptivity (%)	**43**	**28**	**20**	**14**	**10**	**18.1**	**76.7**
JMS 14A	No. of spikelets Cut	72	40	50	55	150	367.0	
	No. of spikelets Set seed	61	19	23	12	4	119.0	
	Stigma receptivity (%)	**85**	**48**	**46**	**22**	**3**	**32.4**	**96.5**
JMS 17A	No. of spikelets Cut	81	131	72	72	96	452.0	
	No. of spikelets Set seed	75	78	43	35	21	252.0	
	Stigma receptivity (%)	**93**	**60**	**60**	**49**	**22**	**55.8**	**76.3**
JMS 18A	No. of spikelets Cut	62	77	120	85	94	438.0	
	No. of spikelets Set seed	47	51	70	19	12	199.0	
	Stigma receptivity (%)	**76**	**66**	**58**	**22**	**13**	**45.4**	**82.9**

angle exposes the stigma more to alien pollens (Kumara *et al.,* 2013).

Stigma exertion is also one of the key traits to be considered for higher hybrid seed yield. Among the genotypes evaluated, stigma exertion varied from 19.0% to 45.7%. CMS 64A (45.7%) was recorded highest stigma exertion followed by CMS 46A (43.7%). Stigma exertion is the highly desirable floral trait as it enhances better out crossing (Sidharthan *et al*., 2007). The rate of exerted stigma, which ranges from 0 to 90%, is correlated with stigma length. Stigma length ranges between 0.4 and 1.6 mm (El-Namaky, 2018). Stigma length is the highly desirable floral trait as it enhances better outcrossing rate(Singh *et al.*, 2003). Nevertheless, CMS 59A showed maximum exerted stigma length (1066.7ìm) followed by CMS 64A (1066 ìm), whereas CMS 14A (529.3 ìm) had lowest exerted stigma length followed by JMS 11A (683.3 ìm).

Soluble sugars ranged from 12.8 mg g^{-1} to 29.1 mg g^{-1}. The CMS 46A recorded the highest soluble sugars (29.1 mg g^{-1}) followed by CMS 23A (28.5 mg g^{-1}). The lowest soluble sugars were found in CMS 14A (12.8 mg g^{-1}) followed by JMS 13A (14.1 mg g^{-1}). Out of 11 CMS lines, ten lines have recorded 0% spikelet fertility with

Table 5: Mean performance of CMS lines for floral traits in rice.

CMS LINES	Duration of glume opening (min)	Angle of glume opening (^{0})	Exerted stigma length (µm)	Stigma exertion (%)	Stigma receptivity (%)	Pollen fertility (%)	Spikelet fertility (%)	Soluble sugars (mg g^{-1})	Panicle length (cm)	Panicle exertion (%)	Natural outcrossing (%)
CMS 11A	156.3	20.0	758.7	19.0	48.0	0.3	0	14.4	21.5	50.8	20.6
CMS 14A	84.0	18.3	529.3	30.7	18.0	1.0	0	12.8	23.8	53.3	15.0
CMS 23A	119.0	26.0	853.3	40.4	71.0	0.7	0	28.5	24.5	73.3	17.8
CMS 46A	171.3	30.3	942.0	43.7	48.6	0	0	29.1	23.3	69.6	37.4
CMS 59A	122.7	30.0	1066.7	40.2	41.2	0.1	0	14.2	22.0	61.1	36.7
CMS 64A	124.0	29.3	1066.0	45.7	36.8	0.3	0	19.1	23.7	65.6	32.9
JMS 11A	120.0	29.0	683.3	29.2	23.0	0.3	0	16.3	25.7	73.6	25.7
JMS 13A	131.3	23.7	926.7	30.1	18.1	0	0	14.1	26.0	61.4	20.9
JMS 14A	129.0	25.3	692.7	30.7	32.4	1.7	0.5	17.6	26.3	71.5	21.8
JMS 17A	59.7	21.7	742.7	35.1	55.8	0.3	0	27.5	23.0	73.6	16.5
JMS 18A	42.7	17.7	726.7	25.9	45.4	0.7	0	18.7	24.3	69.5	12.5
Mean	114.5	24.7	817.1	33.7	39.8	0.6	0.05	20.2	24.0	65.8	23.4
C.V.	11.9	15.2	14.4	14.7	11.4	0.6	-	6.7	8.6	11.0	3.9
C.D. 5%	23.1	6.4	199.7	8.4	7.7	NS	-	2.26	NS	12.3	1.5
S.E ±	7.8	2.2	67.7	2.9	2.6	0.3	-	0.8	1.2	4.2	0.5

Table 6: Correlations between floral traits and outcrossing in rice CMS lines.

Characters	Duration of Glume opening	Angle of Glume opening	Soluble Sugars in florets	Days to 50% Flowering	Panicle Length	Panicle exertion (%)	Plant Height (cm)	Pollen Sterility (%)	Exerted Stigma Length (µm)	Stigma Exertion %	Stigma Receptivity (%)	Natural Outcrossing (%)
Duration of Glume Opening	1	0.6016	0.0073	-0.0074	-0.0743	-0.2180	0.2258	0.2222	0.4255	0.1929	-0.0429	**0.6629***
Angle of Glume Opening		1	0.2589	-0.1086	0.0659	0.3826	0.2237	0.1387	**0.6788***	**0.7182***	0.0603	**0.8798****
Soluble Sugars in florets			1	**-0.6180***	-0.0632	**0.6720***	-0.4772	0.2835	0.1817	0.5379	**0.7696****	0.0827
Days To 50% Flowering				1	0.2521	-0.2758	0.5795	-0.3818	-0.2320	-0.2641	**-0.7721****	0.0898
Panicle Length					1	0.4834	**0.7050***	-0.1890	-0.2655	-0.0677	-0.4285	-0.2596
Panicle Exertion (%)						1	-0.0145	-0.0059	0.0600	0.3901	0.3697	0.0244
Plant Height							1	-0.1293	0.1639	-0.0014	**-0.7212***	0.1511
Pollen Sterility (%)								1	0.3419	0.1027	0.0842	0.1937
Exerted Stigma Length (µm)									1	**0.6547***	0.2449	**0.7446****
Stigma Exertion %										1	0.2871	**0.6353***
Stigma Receptivity (%)											1	-0.0286
Out Crossing %												1

***, ** Significance Levels at 0.05 and 0.01, respectively**

less than 1% pollen fertility, however 'JMS 14A' had recorded 1.7% pollen fertility and 0.5% spikelet fertility which was considered as partial maintainer.

In general panicle exertion will be poor in CMS lines compared to their respective maintainer lines as influenced by cytoplasmicgenes. Among the lines, JMS 11A and JMS 17A were recorded maximum panicle exertion percentage of 73.6%. Higher the panicle exertion higher would be filled grains and leads to better seed yield.

Among the CMS lines, natural outcrossing rate ranged from 12.5% to 37.4%. CMS 46A (37.4%) was recorded highest outcrossing rate followed by CMS 59A (36.7%) indicating that these lines have very good potential to be used as females for commercial exploitation of hybrids with higher seed yields. The success of hybrid rice breeding depends on the extent of outcrossing on CMS lines (Sheeba *et al.,* 2006). However, JMS 18A was found to be very poor with least outcrossing rate (12.5%) followed by CMS 14A (15.0%).Variability in extent of out crossing in rice can be attributed to variations in floral characteristics of varieties and environmental factors(Manonmani *et al.,* 2012).

Correlations between morphological, floral traits and extent of outcrossing rate in rice CMS lines were worked out and presented inTable 6. Outcrossing per cent has highest positive significant correlations with the angle of glume opening (0.8798), exerted stigma length (0.7446), duration of glume opening (0.6629), stigma exertion percentage (0.6353). Stigma receptivity has positive significant correlation with soluble sugar content in florets (0.7696) and negative significant correlation with days to flowering (-0.7721) and plant height (-0.7212). According to Xu and Shen (1988), receptivity was also closely associated with stigmatic characteristics *i.e.* Stigma length and breadth. Stigma exertion makes it possible to breed CMS lines to improve the outcrossing rate.

Soluble sugars also had significant positive correlation with stigma receptivity (0.7696), panicle exertion (0.6720) and significant negative correlation with days to flowering (-0.6180). Angle of glume opening has positive significant correlations with exerted stigma length (0.6788), stigma exertion percentage (0.7182).Variability in extent of out crossing in rice can be attributed to variations in floral characteristics and environmental factors (Manonmani *et al.,* 2012). However, the angle of glume opening exhibited positive but non-significant association with duration of floret opening. Vagolu, (2010) reported that angle of glume opening had significant and positive correlation with duration of glume opening, stigma exertion and outcrossing percentage. Similarly, the duration of floret opening exhibited positive correlation with outcrossing percentage as reported by Singh and Singh (1998).Significant genotypic coefficient of correlation was observed between different floral traits and filled grains per panicle by the earlier reporter, Savitha *et al.* (2017).

Considering floral traits, outcrossing rate and yield contributing traits, CMS 46A, CMS 59A and CMS 64A have been found to be promising for development of hybrids with higher seed yields. These three CMS lines were developed from IRRI, Philippines and being used by many hybrid rice breeding programs. Among them CMS 64 was extensively used and many commercially viable hybrids have been developed and released. Though the stigma receptivity was reasonably high in indigenous bred CMS lines *viz*., JMS 17A and JMS 18A, poor outcrossing rate was attributed due to less duration and angle of glume opening besides poor exerted stigma length. Hence, it could be concluded that though the indigenously developed CMS lines have desirable grain types with acceptable cooking quality parameters, utility of them in hybrid rice development is limited as they had poor outcrossing traits which is very much required. Hence, there isa dire need to develop indigenous CMS lines possessing higher outcrossing ability besides acceptable grain quality parameters like no aroma, intermediate amylose content, slender grain and high yield.

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