Journal of Tropical Agriculture 59 (1): 1-12, 2021

Evaluation of CMS based rice hybrids developed using rice varieties of Kerala as restorers

Nayana Jyothibas and V. G. Jayalekshmy*

College of Agriculture, Kerala Agricultural University, Thiruvananthapuram 695 522, Kerala, India

Received 15 April 2020; received in revised form 03 May 2021; accepted 04 May 2021

Abstract

Hybrid rice is one among the many approaches to break the present yield plateau in rice crop. Red rice is highly preferred by the consumers in Kerala and it therefore warrants that the hybrids developed for the state possess red kernels which would preferably fall into the short to long bold category. The study was undertaken with the objective to evaluate cytoplasmic male sterility based rice hybrids developed using rice varieties of Kerala as restorers, for heterosis for yield and grain quality. Varieties 'Remya' and 'Kanakom' were found to restore the fertility of CRMS31A and CRMS 32A respectively, yielding promising hybrids. Six hybrids along with two checks (Uma and Kanchana) were evaluated in Randomized Block Design (RBD) with three replications. Observations on 12 yield contributing traits and eight grain quality traits were recorded. This evaluation could identify two promising rice hybrids for Kerala i.e., CRMS32A x Kanakom and CRMS31A x Remya which could give yield advantages of 17.91 per cent and 16.37 per cent over the popular rice variety Uma. These two hybrids had long slender grain shape with red kernel colour. The amylose content of these two hybrids was also intermediate. These hybrids had a lower cooking time and good head rice recovery. Standard heterosis of these hybrids over the check variety Uma was positive for all the traits except for pollen fertility and thousand grain weight in the case of the hybrid CRMS 32A x Kanakom.

Key words: Cooking quality, Cytoplasmic male sterile line, Heterosis, Hybrid rice, Restorers.

Introduction

Heterosis breeding is a potential genetic tool that can quicken the yield improvement from 30 to 40 per cent and it advances numerous other desirable quantitative and quantitative characteristics in crops (Srivastava, 2000). The productivity improvement will meet a great part of the extra food demand in future. The present production levels should be raised by 2 million tons to take care of the food demand of the rising population and to sustain food security, and this can be achieved by means of heterosis breeding and other efficient breeding approaches. (Pandey et al., 2010). Use of potential hybrid vigour is considered as one of the scholarly accomplishment of plant breeding in this century.

Rice, being a strictly self-pollinated crop, needs an efficient pollen control system to build hybrids for commercial purpose. Among the different approaches being followed to create hybrid seed in rice, the utilization of Cytoplasmic Male Sterility (CMS) framework is the most pertinent and advantageous and is drawing the attention of breeders because of its straightforwardness and cost adequacy in hybrid seed production. Finding of stable CMS lines and maintainers, identification of restorers, assessment of parental lines and transfer of reliable maintainer lines into CMS lines frame a vital piece of hybrid rice innovation for a productive rice breeding project. The economic exploration of heterosis in rice has been conceivable, essentially, by utilization of Wild Abortive (WA) cytoplasmic/genetic male sterility

*Author for correspondences : Phone:9847202919, Email : jayavgj@yahoo.com

fertility restoration framework (Lin and Yuan, 1980; Virmani and Edwards, 1983).

Rice is a socially important crop of Kerala, the cultivation of which traditionally occupies a prime position in India. The area under rice in Kerala has been declining and rice being the major food of the state, food security is in danger and dependency on other states is increasing. The introduction of hybrids can play a major role to enhance yield and make Kerala self sufficient. An increase in yield of rice hybrids alone cannot provide gain for farmers if grain quality is not acceptable locally and has low demand in the market. Hybrid rice breeding program must give focus to the critical evaluation of hybrids for grain quality before release for commercialization.

In India more than fifty rice hybrids have been released during the past two decades utilizing three line system of hybrid rice production. In Kerala, so far no hybrid rice has been released. The major reason is the non-availability of a heterotic hybrid combination with substantially high yield advantage over the commercially accepted varieties when developed through the three line system. Based on a study undertaken in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, Das (2017) identified some promising hybrids developed from CMS lines (CRMS31A and CRMS32A) with Kerala rice varieties as restorers.

In this context, the present work was undertaken to evaluate the CMS based rice hybrids developed from rice varieties of Kerala as restorers for heterosis for yield and acceptable grain quality.

Material and Methods

The details of the parents and the male sterile line used in the study are given in Table 1.The parents were grown during May to June 2017 and the crossing programme was carried out from July to August, 2017.

Hybrid seed production

CRMS31A and CRMS32A (maintained using CRMS31B and CRMS32B from NRRI, Cuttack) were used as male sterile lines for crossing with the identified restorer lines. Restorer lines were sown in three staggered dates, i.e., one at 10 days before the sowing date of CMS lines, the other along with the CMS lines and the third 10 days after the sowing date of CMS lines. Synchronized flowering dates of the CMS and restorer line were recorded. CRMS31A was crossed with Remya, Jayathy, Swarnaprabha, Kanakom and Neeraja.

The female plants were uprooted from the field at the beginning of blooming. They were planted in pots loaded with mud and kept in polyhouse for anthesis. The CMS plants that indicated clear cut sterility were used for hybridization programme. Pollen sterility test was used to confirm this. Clipping method was utilized for emasculating the

Table 1. Details of the varieties used for the study

Used as	Variety	Source	Description
Female parent	CRMS31A	NRRI, Cuttack	Male sterile line, White kernelled
	CRMS32A	NRRI, Cuttack	Male Sterile line, White kernelled
Male parent	Annapoorna (PTB 35)	RARS, Pattambi	Short duration, Red Kernelled
	Mattatriveni (PTB 45)	RARS, Pattambi	Short duration, Red kernelled
	Swarnaprabha(PTB43)	RARS,Pattambi	Short duration, White kernelled
	Aiswarya(PTB52)	RARS,Pattambi	Medium duration, Red kernelled
	Jayathi (PTB 46)	RARS,Pattambi	Medium duration, White kernelled
	Remya (MO 10)	RRS,Moncompu	Medium duration, Red kerneled
	Kanakom (MO 11)	RRS,Moncompu	Medium duration, Red kernelled
	Neeraja(PTB 47)	RARS, Pattambi	Long duration, white kernelled.
Check varieties	Uma (MO 16)	RRS,Moncompu	Medium duration, Red kernelled
	Kanchana (PTB 50)	RARS,Pattambi	Short duration, Red kernelled

seed parents and hand pollination done by dusting pollen from the male parent. The hybrid seeds were harvested separately from each plant at 21 to 25 days after fertilization. The seeds were dried under sun for 2 to 3 days, packed and labelled.

CRMS32A was crossed with Annapoorna, Aiswarya, Mattatriveni and Kanakom. Hybrid seeds were produced in a total of nine cross combinations. The six specific crosses that had given sufficient number of viable seeds for next season were taken for hybrid evaluation.

Hybrid evaluation

Six hybrids, H1(CRMS31A x Jayathi), H2(CRMS31A x Kanakom), H3(CRMS31A x Remya), H4(CRMS32A x Annapoorna), H5(CRMS32A x Kanakom), and H6 (CRMS32A x Mattatriveni), were evaluated along with check varieties Uma and Kanchana in Randomised Block design with three replications in plots of size 3mx3m at IFSRS Karamana during October 2017 to January 2018 (Mundakan, 2017-18). The site was located geographically at 11^{o}N latitude and 77^{o}E longitude at an altitude of 5 m above mean sea level. The seeds were germinated in petri plates lined with water-soaked tissue paper. The germinated hybrid seeds along with two checks were planted in dapong trays of size 60 cm x 30 cm filled with field soil at a spacing of 5 cm between plants. Irrigation was done as required. The field was well prepared and leveled for rice transplanting and good irrigation facility was also provided. Field experiment comprising of six F_1s and two checks viz., Uma and Kanchana were utilized to assess the heterosis. Twenty-one days old seedlings were transplanted to main field at a spacing of 20 cm x 15 cm in plots of size 3 m x 3 m.

Farm yard manure @ 5 t/ha was added to all the plots uniformly. The fertilizer recommendation of 70 kg N, 35 kg P_2O5 and 35 kg K_2O per ha was adopted for short duration varieties, while 90 kg N, 45 kg P_2O5 and 45 kg K_2O per ha was applied for medium duration varieties (KAU, 2016), and 150 kg N, 75 kg P_2O5 and 75 kg K_2O per ha for all the hybrids (Mohan and Pillai, 2014). Irrigation and drainage channels were also provided. Thinning and gap filling were done at 30 days after sowing (DAS) to maintain uniform population at one seedling per hill. One hand weeding was done at 30 DAS and another at 60 DAS. Prophylactic sprays of Fame®, 1ml/10L against leaf roller and stem borer, K cyclin®, (2g/L) against bacterial leaf blight and Fenwal®, 1ml/L against rice bug were applied. The crop was harvested in February, 2018. Plants in one border row onall sides of each plot were harvested first and removed. Net plots were harvested by cutting the plants at the base. Threshing was done manually and the produce was cleaned, dried and weighed. Weight of grain was expressed as kg per plot.

Cooking quality analysis

Grain samples were analyzed for optimum cooking time after milling (Hirranniah et al., 2001). Volume expansion was assessed using water displacement method (Julianao, 1971). As per Khan et al.(2003), kernel length and breadth were calculated using Dial Vernier Calipers. Kernel length by breadth ratio was determined according to the classification of SES, IRRI (2002). Kernel colour was observed and classed as red and white. Amylose content was analyzed according to Perez and Juliano (1978) and classified accordingly. The starchy endosperm was rated visually based on a seven point numerical spreading scale as in standard evaluation system for rice. According to Alkali Spreading Value Score, gelatinization temperature of rice grains was classified into respective group.

Estimation of heterosis

Heterosis expressed as per cent of increase or decrease in the performance of F_1 hybrid over check parent (standard heterosis) was calculated as per the methods of Hayes et al. (1995).

Results and Discussion

Synchronization of flowering of the parents is an essential step in hybrid seed production. Staggered sowing of the parents could identify the appropriate date of sowing of male parents in order to get synchronization of flowering with the male sterile female parents. Hybrid seed production was done in nine hybrids using hand emasculation clipping method and six hybrid combinations which produced more than 1500 seeds were selected for evaluation. Among nine hybrids, five male parents that were sown along with CMS line obtained synchronization in flowering (Table 2). For three hybrids, the male parents which were sown 10 days after CMS got synchronized flowering. In one cross combination (Neeraja with CRMS31A), synchronized flowering was obtained for the male parent which was sown ten days before CMS lines. Virmani (1997), in his manual of Hybrid Rice Breeding Technology, had stressed the necessity for staggered sowing of the male parents in order to get synchronization of flowering for effective seed production. The male sterile lines CRMS31A and CRMS 32A could be maintained for next season of seed production by the respective B lines.

A hybrid with the potential of being released for commercial cultivation should significantly surpass the yield level of the best locally adapted variety and at the same time ensure hybrid seed production in bulk quantities. Hand emasculation method by clipping was found to be an efficient method for getting hybrid seeds. But the recovery of hybrid seed was less and so it could not be advocated for commercial hybrid seed production. There is a necessity for standardization of technique for hybrid seed production of rice in Kerala in order to find out the best location, season and method.

Table 2. Synchronization of flowering of restorers with CMS lines

Female parent (CMS lines)	Male parents (Restorers)	Sowed 10 days before CMS	Sowed along with CMS	Sowed 10 days after CMS
CRMS31A	Remya		✓	
	Jayathy		✓	
	Swarnaprabha			✓
	Kanakom			✓
	Neeraja	✓		
CRMS32A	Annapoorna			✓
	Aiswarya		✓	
	Mattatriveni		✓	
	Kanakom		✓	

Mean performance of hybrids and checks

Among the six hybrids, H5 (CRMS32A x Kanakom), H3 (CRMS31A x Remya), and H1 (CRMS31A x Jayathi) gave higher yield than the standard check Uma (Table 3). The yield component traits number of productive tillers and panicle length were also significantly higher than that of the check variety Uma.

Kumar et al. (2010) also reported the better performance of hybrids for yield related traits. Pollen fertility of H5 was superior to the standard check. This showed that the variety Kanakom was a complete restorer for male sterile cytoplasm CRMS32A.Hybrid H3 also showed pollen fertility on par with the check. Hence the variety Remya was a restorer for CRMS31A. The other hybrids H4 and H6 had pollen fertility per cent of around 50. So the male parents Annapoorna and Mattatriveni for CRMS32A could be considered as partial restorers. The low level of pollen fertility was the reason for low yield of hybrids H4 and H6 despite high number of productive tillers. The hybrid H1 gave on par yield with Uma even though the pollen fertility was considerably lower. Singh et al. (2006) also reported a similar case. The variations in behavior of fertility restoration indicated that either the fertility-restoring genes were different or that their penetrance and expressivity varied with the genotypes of the parents or by presence of modifiers in female background. For days to maturity, the hybrids H1 and H2 were on par with Uma, whereas the hybrids H4 and H6 matured earlier than the standard check Kanchana. The male parent of hybrid H4 was

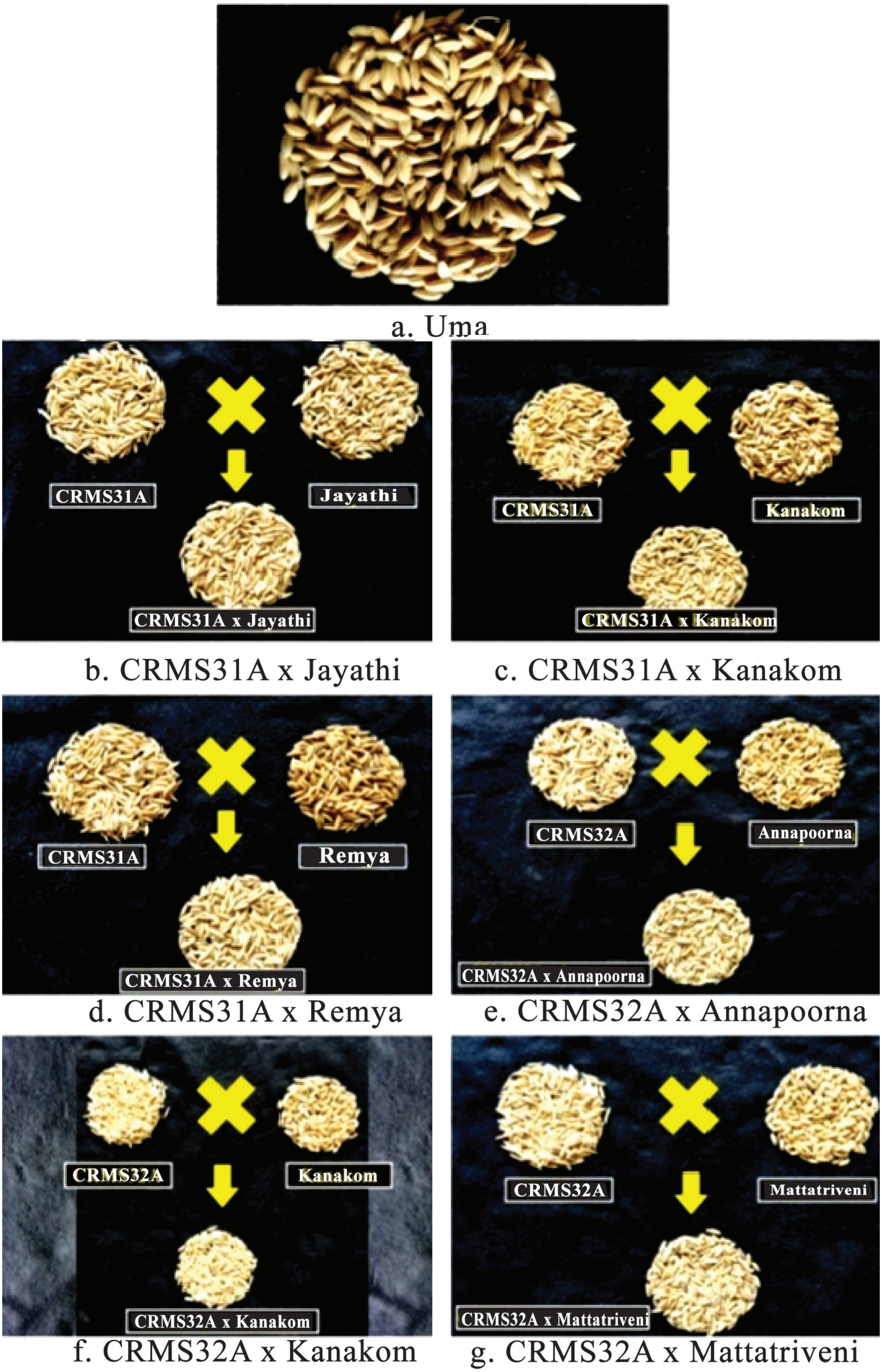

Plate 1. Grains of hybrids with that of parents and check

a. CRMS31A x Jayathi
b. CRMS31A x Kanakom
c. CRMS31A x Remya
d. CRMS32A x Annapoorna
e. CRMS32A x Kanakom
f. CRMS32A x Mattatriveni

Plate 2. Panicles of hybrids along with that of check and restorers

Annapoorna which had a short duration of 95days. From the evaluation of hybrids it was seen that the duration of male parent decided the duration of hybrids. The thousand grain weight was lower for all the hybrids except H3. This trait of H2 (CRMS31A x Remya) was on par with that of Uma. But the 1000 grain weight for the hybrids H5, H4, H6 and H1 registered a lower value.

Quality is an important trait in rice breeding programme. Rice being the staple food in many countries, the consumer preference of quality also varies with the area of cultivation. Better quality rice gives better returns to farmers. Hence rice with better yield and quality must be preferred for breeding works. The analysis of quality parameters in rice grains of hybrids revealed that the hybrids showed variation from the standard check in most of the traits such as kernel length, kernel breadth, kernel length by breadth ratio, head rice recovery

Table 3. Mean performance of hybrids and check varieties for yield and yield parameters

Treatments	PH	TN	DF	PL	PF	SPP	DM	FGPP	TGW	GYPP	YPP
C1	94.48	8.84	87.00	22.67	82.67	164.33	119.00	141.67	22.83	27.97	3.41
C2	86.52	8.73	77	20.5	72.94	77.83	109	71	27.27	16.5	2.24
H1	101.1	9.90	87.33	24.33	77.31	163.67	122.67	138.00	19.27	30.08	3.67
H2	104.82	9.93	86.67	24.33	75.36	293.33	118.67	179.00	22.83	25.40	3.00
H3	98.04	10.47	79.00	26.00	85.67	220.00	113.67	168.50	23.27	32.54	3.97
H4	85.00	11.86	63.00	29.33	47.33	219.00	94.67	43.67	20.63	6.61	0.76
H5	109.73	10.33	82.67	27.17	79.12	240.00	118.00	184.00	21.50	32.97	4.02
H6	99.06	11.62	67.67	29.53	48.35	183.5	103.00	54.30	20.40	8.54	1.04
Mean	97.34	10.21	78.79	25.48	71.09	195.21	112.34	122.52	22.25	22.58	2.76
SE (m)	2.13	0.78	0.63	0.97	1.24	18.29	2.04	1.03	0.81	4.17	0.26
CD (0.05)	4.64	1.69	1.36	2.12	2.7	39.85	4.45	2.25	1.76	9.09	0.56

PH- Plant height (cm), TN- Number of productive tillers per plant, DF- Days to flowering, PL- Panicle length (cm), PF- Pollen fertility (%), SPP- Number of spikelets per panicle, DM- Days to Maturity, FGPP- Number of filled grains per panicle, GLBR- Grain length by breadth ratio, TGW- Thousand grain weight (g), Grain yield per plant (g), YPP-Yield per plot (kg).

C1-Uma,C2-Kanchana,H1(CRMS31Ax Jayathi),H2(CRMS31A x Kanakom), H3(CRMS31A x Remya),H4(CRMS32A x Annapoorna),H5(CRMS32A x Kanakom), H6 (CRMS32A x Mattatriveni)

in milling, optimum cooking time, volume expansion, amylose content and gelatinization temperature.

All the hybrids had significantly less cooking time than that of the variety Uma (Table 4). Sathyan (2012) reported a cooking time of 29.33 minutes for the variety Jyothi which was another popular rice variety of Kerala. In this study, hybrids H4, H6, H1, and H5 had lower cooking time of around 25 minutes. Lii et al. (1996) expressed that amylose content was considered as the single most important character for cooking and processing behavior of rice. Hamaker and Griffin (1990) also reported that cooking and eating qualities of rice was directly associated with the amylose content. Most of the hybrids were in the class intermediate (as per SES manual) along with that of that of the standard check. Amylose content of hybrids H5 and H6 were on par with the standard check variety Uma. H4 showed a higher value and H3, H4 and H6 showed lower values of amylose content. Azabagaoglum and Gaytancioglu (2009) and Musa et al. (2011) disclosed that consumer preference varied based on the type of rice and their origin. Lyon et al. (2000) claimed that rice texture was a key indicator of rice quality as it affected acceptance of cooked rice by consumers. Traditionally, Keralites prefer non sticky bold to medium red kernelled rice with hard and dry texture. The amylose content of these

Table 4. Mean of hybrids and checks for grain quality parameters

Treatments	OCT	VEX	KL	KB	KLBR	HRRM	AC	GT
C1	29.67	2.85	5.16	2.48	2.08	55	25.14	4.33
C2	31	3.22	6.3	2.15	2.94	59.2	24.18	3.33
H1	25.67	3.02	6.09	2.49	2.46	60.00	26.08	3.33
H2	24.00	3.48	7.02	2.18	3.24	49.00	25.76	5.00
H3	22.00	3.63	6.90	2.04	3.52	43.00	24.48	5.67
H4	25.67	2.92	6.13	2.24	2.75	45.00	27.28	5.33
H5	25.00	2.94	6.90	2.05	3.41	57.30	22.55	6.00
H6	25.67	3.30	6.39	2.21	2.89	59.00	21.78	5.67
Mean	26.09	3.17	6.36	2.23	2.91	53.44	24.66	4.83
SE (m)	0.80	0.07	0.25	0.11	0.25	2.05	1.04	0.39
CD (0.05)	1.75	0.15	0.55	0.24	0.55	4.47	2.25	0.85

OCT- Optimum cooking time, VEX- Volume expansion, KL- Kernel length (mm), KB- Kernel breadth (mm), KLBR- Kernel length by breadth ratio, KC- Kernel colour, HRRM- Head rice recovery in milling (%), AC- Amylose content (%), GT- Gelatinization temperature.

C1-Uma,C2-Kanchana,H1(CRMS31AxJayathi),H2(CRMS31AxKanakom),H3(CRMS31Ax Remya),H4(CRMS32A x Annapoorna),H5(CRMS32A x Kanakom), H6 (CRMS32A x Mattatriveni) hybrids showed that the cooking quality of the hybrids was on par with that of Uma. Aliawati (2003) reported that high amylose content gave hard and dry texture to cooked rice.

Volume expansion of H5 and H4 were on par with that of variety Uma. Gelatinization temperature of all the hybrids except H1 and H5 were on par with that of Uma. H5 registered low and H1 high gelatinization temperatures. This study proved that the chemical qualities of rice grains of the hybrids were acceptable to the consumers of Kerala as the values were similar to the most accepted commercial variety of Kerala, Uma.

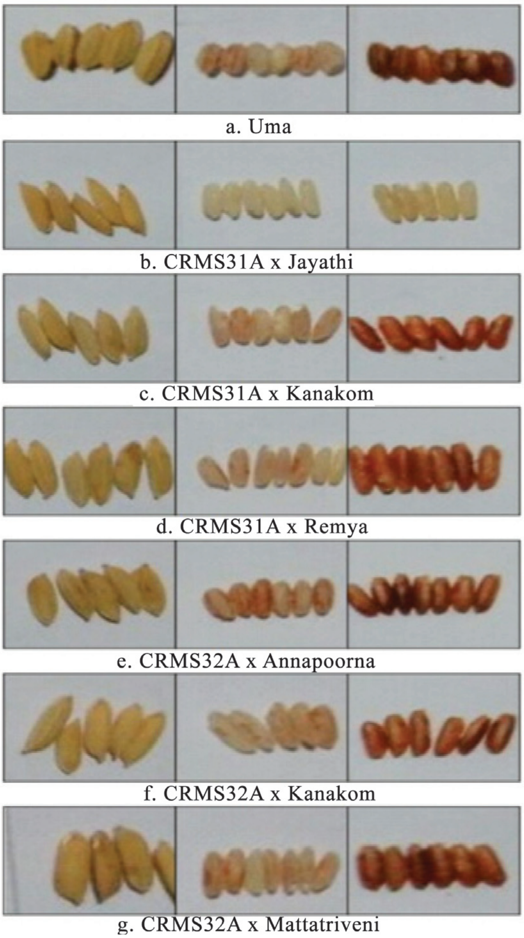

Plate 3. Whole grain, milled and kernelled grains of check and hybrids

Keralites are very specific for their preference to red kernel colour. Five out ofsix hybrids had kernel colour similar to Uma. H1 was white kernelled as its male parent Jayathy was white kernelled. In this study it was seen that the hybrids inherited the kernel colour of the male parent or it may be assumed that red colour was dominant over white. But Vanaja (1998) concluded that pattern of inheritance of kernel colour in rice was a complex qualitative character. She also reported that each red and white colour might be separately controlled by two or more sets of genes having both inhibitory and duplicate type of gene interactions with predominance of inhibitory type gene interaction.

Keralites also have a specific preference for shape of the grains. They prefer bold to medium shaped grains. The kernel length breadth ratio of all the hybrids were slightly higher than that of Uma except for the hybrid H1.The hybrids H1, H6 and H4had medium grain shape (kernel length breadth ratio 2.1 to 3) even though the grains were slightly longer than that of Uma which is also a medium grain shaped variety (Table 5). The hybrids H3 and H5 registered the grain shape of female parent i.e., long slender. Breadth of the kernel of all the hybrids except H1 was lower than that of Uma. This might be the reason for the phenomenon of curling noted in cooked rice of hybrids.

Standard heterosis

Standard heterosis was calculated over the check variety Uma. All the hybrids showed positive heterosis for plant height compared with that of Uma except H4 (Table 6). In 1980, Lin and Yuan reported that the hybrids showed better lodging resistance than their parents in spite of slightly taller stature. In this study also it was found that the hybrids were resistant to lodging despite tall stature. Stronger root system and thicker culm of hybrids might be responsible for their lodging resistance.

In the case of number of productive tillers, all the hybrids showed higher positive standard heterosis. H4 and H6 showed significant results for this trait.

Table 5. Classification of hybrids and check as per Standard Evaluation System, IRRI (2002)

Hybrids	Kernel length	Kernel length by breadth ratio	Amylose content	Gelatinization temperature
C1	Medium	Medium	Intermediate	Intermediate(70°c-74°c)
H1	Medium	Medium	Intermediate	High, Intermediate
H2	Medium	Slender	Intermediate	Intermediate(70°c-74°c)
H3	Long	Slender	Intermediate	Intermediate(70⁰c-74°c)
H4	Medium	Medium	Intermediate	Intermediate(70⁰c-74°c)
H5	Long	Slender	Intermediate	Low(55°c-69°c)
H6	Medium	Medium	Intermediate	Intermediate(70⁰c-74°c)

C1 Uma, H1(CRMS31Ax Jayathi), H2(CRMS31A x Kanakom), H3(CRMS31A x Remya), H4(CRMS32A x Annapoorna), H5(CRMS32A x Kanakom), H6 (CRMS32A x Mattatriveni)

Joshi et al. (2004) reported that standard heterosis of number of tillers per plant ranged from 22.22 to 81.48. Increase in panicle number (productive tillers) was earlier observed by Singh and Singh (1980) and Anandakumar and Rangasamy (1986), whereas Virmani et al. (1981, 1982) and Jennings (1967) reported negative heterosis for panicle number in the hybrids.

Only H4 and H6 showed significant negative heterosis for days to flowering compared with standard check Kanchana while all the other hybrids were later flowering than the short duration check. All the hybrids flowered within 63 to 87 days. According to Virmani (1982) the high yielding hybrids flowered within 71 – 91 days, indicating that growth duration did not limit the yield potential of hybrids and the hybrids tended to show more earliness than their parents but their height was either comparable or slightly taller than their parents in the tropics in wet season.

Two out of six hybrids were earlier maturing than the variety Kanchana. According to Virmani (1987), hybrids were observed to possess varying growth duration ranging from 105 to 136 days. The present study registered a duration ranging from 94 to 122 days. Hybrid vigour for panicle length was noticed in all the crosses but only the hybrids H4, H5 and H6 showed significant standard heterosis. Singh et al. (1980) reported similar results.

Significantly high value of standard heterosis was reported for the trait number of spikelets per panicle for all the hybrids except H1. Results obtained in China and at IRRI indicated that heterotic F_1combinations usually showed an increased sink size through an increase in spikelet per panicle (Virmani and Edwards, 1983).There were no positive significant heterobeltiosis and standard heterosis for spikelet fertility percentage.

Table 6. Standard heterosis of the hybrids over the check variety Uma

Hybrids	PH	TN	DF	PL	PF	SPP	DM	FGPP	TGW	GYPP	YPP
H1	6.98	12.5	12.93*	7.35	-6.48	-0.41	12.53*	-2.588	-15.62	7.54	7.58
H2	10.93	12.87	12.07	7.35	-8.83	78.49	8.87	26.588	0.01	-9.18	-9.12
H3	3.76	18.94	2.16	14.7*	3.63	33.87	4.28	18.94	1.898	16.33	16.37
H4	-10	34.85*	-18.53**	29.4**	-42.74**	33.67	-13.15*	-69.18**	-9.635	-77.6**	-76.37**
H5	16.13	17.42	6.9	19.85*	-4.29	46.15**	8.25	29.88	-5.839	17.87	17.91
H6	4.84	31.8*	-12.49*	30.15**	-41.51**	11.66	-5.50	-61.67*	-10.65	-69.92**	-69.45**

H1(CRMS31AxJayathi), H2(CRMS31AxKanakom), H3(CRMS31AxRemya), H4(CRMS32Ax Annapoorna),H5(CRMS32A x Kanakom), H6 (CRMS32A x Mattatriveni)

PH- Plant height (cm), TN- Number of tillers per plant, DF- Days to flowering, PL- Panicle length (cm), PF- Pollen fertility (%), SPP- Number of spikeletsper panicle, DM- Days to Maturity, FGPP- Number of filled grains per panicle, GLBR- Grain length by breadth ratio, TGW- Thousand grain weight (g), Grain yield per plant (g), YPP-Yield per plot (kg)

*Significant at 0.05 level **Significant at 0.01 level.

Three hybrids showed negative and other three showed positive heterosis for number of filled grains per panicle. The highest positive heterosis was shown by H5 (29.88), followed by H2 (26.58) and H3 (18.94).According to Virmani et al. (1981), non significant positive or negative heterosis for number of filled grains per panicle could be noticed and they concluded that even though the hybrids had fewer effective panicles per square meter, they had significantly more filled grains per panicle and larger seeds.

All the hybrids except H5 failed to show positive heterosis for pollen fertility. Non significant positive or negative heterosis for this trait was reported by Virmani et al. (1981).

Even though the number of spikelets per panicle was high, insufficient restoration of fertility paved the way for chaffiness of spikelets which in turn reduced the potential of hybrid to register further higher number of filled grains per panicle. High number of ear bearing tillers per plant was observed in H4 and H6, however presence of high heterosis for this trait could not result in higher yield, especially in hybrids where spikelet sterility was greatly affected due to varying levels of fertility restoration. Therefore due consideration was required for both panicles per plant and spikelet fertility simultaneously (Virmani et al., 1981).

Three hybrids showed positive heterosis for yield per plot. The highest positive heterosis was observed by H5 (17.9) followed by H3 (16.37), and H1 (7.58). Positive heterosis in the yield contributing traits reported in these hybrids with good spikelet fertility would have led to heterotic yield.

The higher length of grain for the hybrids paved the way to significantly higher value of standard heterosis for length-breadth ratio of grain. All the hybrids except H3 registered negative heterosis for 1000 grain weight. Grain yield per plant showed almost same value of standard heterosis as that of yield per plot. The hybrids H1, H3 and H5 showed high estimated value of standard heterosis. Of these H2 and H5 had the common male parent Kanakom which showed that the variety Kanakom was a good combiner with the CMS line to give high heterosis for yield. Most crosses showing significant standard heterosis for yield were found to be possessing heterosis for more than one component. Standard heterosis with respect to grain quality parameters are indicated in Table 7.

None of the hybrids showed heterosis for all the studied characters. Same results were also reported by Maurya and Singh (1978) and Virmani et al. (1982). Hence from the results it was obvious that hybrid vigour for yield was the result of interaction of simultaneous increase in the expression of yield components.

The evaluation of hybrids could identify two promising hybrids for Kerala, H5 (CRMS32A x

Table 7. Standard heterosis of hybrids for grain quality parameters over the check variety Uma

Hybrids	OCT	VEX	KL	KB	KLBR	HRRM	AC	GT
H1	-13.48*	6.05	18.078	0.89	17.9	9.09	3.72	-23.08
H2	-19**	22.31**	36.19**	-12.16	55.28*	-10.9	2.46	15.38
H3	-25.84**	27.5**	33.8**	-17.67*	69.07**	-21.8**	-2.62	30.77*
H4	-13.48*	2.65	18.89*	-9.64	32.2	-18.18	8.5	23.08
H5	-15.73*	3.09	34.02**	-17.27*	63.44*	4.24	-10.3	38.46*
H6	-13.48*	16.08**	23.9*	-10.86	39.09	7.27	-13.36	30.77*

H1(CRMS31AxJayathi),H2(CRMS31AxKanakom),H3(CRMS31AxRemya),H4(CRMS32Ax Annapoorna),H5(CRMS32A x Kanakom), H6 (CRMS32A x Mattatriveni)

OCT- Optimum cooking time, VEX- Volume expansion, KL- Kernel length (mm), KB- Kernel breadth (mm), KLBR- Kernel length by breadth ratio, KC- Kernel colour, HRRM- Head rice recovery in milling (%), AC- Amylose content (%), GT- Gelatinization temperature.

*Significant at 0.05 level**Significant at 0.01 level

Kanakom) and H3 (CRMS31A x Remya), with 17.91 and 16.37 per cent yield advantage respectively over the popular rice variety Uma. According to Virmani (1996), hybrid rice varieties with a yield advantage of 15-20 per cent over the conventional high yielding varieties can be released for commercial production. These two hybrids had medium grain shape with red kernel colour. The amylose content and gelatinization temperature of these two hybrids were on par with that of the variety Uma. These hybrids had lower cooking time and good head rice recovery. With better agronomic practices and productive soil still higher yield can be expected. These two hybrids can be recommended for Kerala after trials over locations and seasons. Better seed production techniques have to be standardized before commercial release.

Acknowledgement

We thank Kerala Agricultural University State Plan for funding. We thank National Rice Research Institute, Cuttack (NRRI; formerly Central Rice Research Institute), RARS, Pattambi and RRS, Moncompu for providing seeds. Also thanking the faculty of IFSRS, Karamana for assisting in field level evaluation.

References

Aliawati, G. 2003. Analysis techniques levels of amylose in rice. Bull. Agric. Eng., 8 (2): 82-84.

Anandkumar, C. R. and Rangasamy, S. R.S. 1986. Heterosis and inbreeding depression in rice. Oryza, 23: 96-101.

Azabagaoglum, O. and Gaytancioglu, O. 2009. Analyzing consumer preference to different rice varieties in Turkey. Agric. Tropica et Subtropica, 42:118-125.

Das, R. 2017. Genotyping of *Rf* (Restoring fertility) loci of rice varieties of Kerala using molecular markers. Ph. D (Ag) thesis, Kerala Agricultural University, Thrissur, 69p.

Hamaker, G. T. and Griffin, S. 1990. Hardness and sickness of cooked rice as indicators of eating quality. J. Food Sci., 55: 1180-1182.

Hayes, M. M., Faridi, M. N., Razzaque, C. A. and Newaz, M. A. 1995. Combining ability for yield and component characters in rice. Indian J. Agric. Sci., 51(10):711-714.

Hirannaiah, B. V., Bhashyam, M. K. and Ali, S. Z. 2001. An improved cooking quality test for Basmati rice. J. Food Sci. Technol., 38: 116–119.

IRRI . 2002. Standard Evaluation System for Rice. International Rice Research Institute, Manila, 56p.

Jennings, P. 1967. Rice heterosis at different growth stages in tropical environment. Int. Rice Comm. News, 16: 24-26.

Joshi, K. B., Laxmi, S. P., Santa Gurung, B. S., and Sharma, C. R. 2004. Evaluation of cultivars and land races of rice (*Oryza sativa* L.) for restoring and maintaining wild abortive cytoplasm. Himalayan J. Sci., 12:170-178.

Juliano, B.O. 1971. A simplified assay for milled rice amylose. Cereal Sci. Today, 16(10): 334 - 340.

KAU. 2016. Package of Practices Recommendations: Crops (15th Ed.). Kerala Agricultural University, Thrissur, 360p.

Khan, M. A., Jorder, O. I., and Eunus, A. M. 2003. Heterosis and combining ability in diallel cross of rice (*Oryza sativa* L.). Bangladesh J. Agric. Sci., 4: 137–145.

Kumar, S., Singh, H. B., Sharma, J. K. and Sood, S. 2010. Heterosis for morpho- physiological and qualitative traits in rice. Oryza, 47(1).

Lii, C. Y., Tsai, M. L. and Tseng, K. H. 1996. Effect of amylose content on the rheological property of rice starch. Cereal Chem., 73 (4): 415–420.

Lin, S.C. and Yuan, L.P.1980. Hybrid Rice Breeding in China. In Innovative Approaches to Rice Breeding. International Rice Research Institute, Manila, Philippines. 351p.

Lyon, B. G., Champagne, E. T., Vinyard, B. T. and Windham, W. R. 2000. Sensory and instrumental relationships of texture of cooked rice from selected cultivars and post harvest handling practices. Cereal Chem., 77(1): 64-69.

Maurya, D. M. and Singh, D. P. 1978. Heterosis in rice. Indian J. Genet. Plant Breed., 38: 71-76.

Musa, M., Othman, N., and Fatah, F. A. 2011. Determinants of consumers purchasing behavior for rice in Malaysia. Am. Int. J. Contemporary Res., 1 (3): 159-163.

Mohan, S. S. and Pillai, S. S. 2014**.** Effect of spacing, seedling density and nutrient management on the performance of hybrid rice (*Oryza sativa* L.) in Southern Kerala. Curr. Adv. Agric. Sci., 6(2): 193-195.

Pandey, P., Yadav, S. K., Suresh, S. G., and Kumar, B.

2010. Assesment of genetic variability, correlation and path association in rice (*Oryza sativa* L.). Oryza, 18: 1-18.

Perez, C. M. and Juliano, B. O. 1978. Modification of the simplified amylose test for milled rice. Starch-Starke, 30:424-426.

Sathyan, N. T. 2012. Quality evaluation of germinated rice and rice products. M. Sc. (Home Science) thesis, Kerala Agricultural University, Thrissur, 97p.

Singh, S. P. and Singh, H. G. 1980. Heterosis in rice. Oryza, 15: 173 -175.

Singh, R. V., Verma, O. P., Dwivedi, J. L., and Singh, R. K. 2006. Heterosis studies in rice hybrids using CMS systems. Oryza, 43(2): 154-156.

Srivastava, M. N. 2000. Heterosis in rice involving parents with resistance to various stresses. Oryza, 19: 172-177.

Vanaja, T. 1998. Genetic analysis of high yielding rice varieties of diverse origin. Ph. D (Ag) Thesis, Kerala Agricultural University, Thrissur, 58p.

Virmani, S. S. 1987. Hybrid Rice Breeding. Hybrid Seed Production of Selected Cereal, Oil and Vegetable Crops. FAO, Rome. pp.35-53.

Virmani, S. S. and Edwards, I. B. 1983. Current status and future prospects for breeding hybrid rice and wheat. Adv. Agron., 36: 145–214.

Virmani, S. S., Aquino, R. C., and Khush, G. S. 1982. Heterosis breeding in rice (*Oryza sativa* L.). Theor. Appl. Genet., 63: 373-380.

Virmani, S. S., Chaudhary, R. C., and Khush, G. S. 1981. Current outlook on hybrid rice. Oryza, 18**:** 67-84.

Virmani, S. S. 1996. Hybrid rice. Adv. Agron., 57:328-462.

Virmani, S. S., Virakamath, B. C., Laral, C. L., Toledo, R. S., Lopez, M. T., and Manalo, J. O. 1997. Hybrid Rice Breeding Manual. Manila. Int. Rice Res. Notes. 151p.