EVALUATION OF CMS BASED RICE HYBRIDS DEVELOPED FROM RICE VARIETIES OF KERALA IDENTIFIED AS RESTORERS

by

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DECLARATION

I, hereby declare that this thesis entitled "**EVALUATION OF CMS BASED RICE HYBRIDS DEVELOPED FROM RICE VARIETIES OF KERALA IDENTIFIED AS RESTORERS**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

^0C	Degree Celsius
%	Per cent
CD	Critical Difference
cm	Centimetre
mg	Milligram
RBD	Randomised Block Design
DAS	Days After Sowing
et al.	And others
Fig.	Figure
g	Gram
g^{-1}	Per gram
Kg	Kilo gram
ha^{-1}	Per hectare
KAU	Kerala Agricultural University
t ha^{-1}	Tonne per hectare
kg ha^{-1}	Kilogram per hectare
kg $plot^{-1}$	Kilogram per plot
$Plant^{-1}$	Per plant
$Plot^{-1}$	Per plot
Temp.	Temperature
Via	Through

mm	millimetre
mm^3	millimetre cube
No.	Number
M	Molar
Sl.	Serial
sp. or spp.	Species (Singular and Plural)
GCV	Genotypic Coefficient of Variation
PCV	Phenotypic Coefficient of Variation
viz.	Namely
d.f	Degrees of freedom
S. E	Standard Error
mg g^{-1}	Milligram per gram
g day^{-1}	Gram per day
IRRI	International Rice Research Institute
USA	United States of America
WA	Wild Abortive
F_1	First generation
UNTP	United Nations Transitional Plan
MAHYCO	Maharashtra Hybrid Seeds Company
NATP	National Agricultural Technology Project
IARI	Indian Council of Agricultural Research
m.ha	Million hectare
m. tons	Million tons

CMS	Cytoplasmic Male Sterile
$plant^{-1}$	per plant
per se	Average
$panicle^{-1}$	per panicle
BPH	Brown Plant Hopper
L.	Linnaeus
L/B	Length by breadth
am.	Ante meridiem
ml/l	millilitre per liter
g/L	gram per liter
kw	kilowatt
SES	Standard Evaluation System
NaOH	Sodium hydroxide
w/v	Weight by volume
nm	nano meter
cm	centimeter
KOH	Potasium hydroxide
h	hour
NRRI	National Rice Research Institute

INTRODUCTION

1. INTRODUCTION

Rice (*Oryza sativa* L.) has an important role in agriculture in India with 44 million hectares (22%) of the cropped area and a production of 101.80 million tons. It is the staple food for more than 2/3 rd of the Indian population meeting around 43 per cent of their calorie requirement. The rate of increase in rice production in India is recorded as 1.7 per cent from 1983 to 2013. At present, India is producing about 106.19 million tons of rice a year from 44 million hectare of land. India ranks 27th out of 47 countries with yield rate of 2.4 t ha^{-1}. Leading countries like China and Brazil have a productivity of 4.7 t $ha^{-1}$and 3.6 t ha^{-1} respectively (INDIASTAT, 2016).

With a specific end goal to meet the prerequisites of the developing population, a dire need to expand rice production must be done. To limit the gap between production and requirement, an expansion in productivity is the rest of the choice. Exploitation of heterosis using hybrid rice technology has been enrolled as a potential procedure for setting off the productivity in rice. The average yield of hybrid rice is 15-20% more than that of inbred rice. On other hand, it has been foreseen that hybrid rice innovation will assume a key part in guaranteeing food security, around the world in later on decades (FAO, 2014).

Heterosis breeding is a potential genetic tool that can quicken the yield improvement from 30 to 40 % 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 lifted by 2 million tons consistently to take care of the food demand of the rising population and to pick up food security, which can be achieved by means of heterosis breeding and other efficient breeding approaches. (Pandey *et al*., 2010). Use of potential hybrid vigour is taken 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 pulling in the consideration of breeders because of its straightforwardness and cost adequacy in hybrid seed production. Finding of stable CMS lines, maintainers, identification of restorers, and assessment of parental lines and transfer of reliable maintainer lines into CMS lines frames 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 fertility restoration framework (Lin and Yuan, 1980; Virmani and Edwards, 1983).

Extensive research work is being carried out throughout India and in other foreign countries on various aspects of hybrid rice. On a commercial scale, several novel hybrids have expressed yield advantage of around 20 per cent over current three line hybrids. The average yield of rice hybrids is 6.3 tha^{-1} while that of the inbred varieties is 4.5 tha^{-1}. Hence, breeders are now trying to develop improved hybrids for different ecological condition and to find out suitable agronomical practices together with adequate supply of seeds by producing quality seeds of concerned hybrids (Throat *et al.*, 2017).

Rice is a socially important crop of Kerala, the cultivation of which traditionally occupies a prime place in India. The area under rice in Kerala has been declining, with a high probability of fragmentation of paddy farming. Since rice is the major food of the state, food security is at danger and dependency on other neighbouring states is increasing. To feed the population of 3.2 crores, 38-40 lakh tons of food grains each year is required with a per capita food accessibility of 320 g day^{-1}. The actual production is only around 6 lakh ton which is less than $1/6^{th}$ the requirement. As a result, 85 per cent of food grain requirement of Kerala comes from neighbouring states. Keralites have a strong consumer preference for red carpelled course grained rice varieties which is more nutritious. Since Kerala is the only state which develops and releases red kernelled rice varieties on a routine basis, the hybrid for Kerala must be red kernelled. An increase in yield of rice hybrids alone can't provide gain to farmers if their grain quality isn't adequate locally and they have low request in the market. Hybridity as such won't influence grain quality both as per physical and chemical characters, if the two parents have ideal grain quality. Hybrid rice breeding program must offer attention regarding the basic evaluation of hybrids for grain quality before release for commercialization.

Appearance of the rice grain is a noteworthy issue of rice production in many rice producing regions of the world, especially in hybrid rice production of Kerala (Vanaja and Babu, 2004). Based on a work undertaken in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, Das (2017) has identified some promising hybrids developed from CMS lines (CRMS31A and CRMS32A) with Kerala rice varieties as restorers.

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

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Trend of plateauing in the yield of HYV (High Yielding Varieties), decreasing and fragmenting natural resources like land and water and high shortage of labour make the task of increasing rice production more challenging in Kerala. According to Viraktamath (2010), besides crop management, the innovative genetic option of hybrid rice technology is practically more feasible and readily adoptable. In the current scenario, since Kerala is not self sufficient to feed its population, the introduction of a hybrid can play a major role to enhance yield production. Standard heterosis over the locally adopted high yielding check variety, heterobeltiosis and grain quality parameters are the important aspects to be considered in the development of hybrid rice for Kerala. The literature available in these aspects is reviewed under the following heads

2.1 Hybrid rice

2.1.1 Three line Breeding

2.2 Heterosis

2.3 Grain quality parameters

2.1. HYBRID RICE

With the first report on heterosis (Jones, 1926) and the knowledge on the role of cytoplasm in induction of male sterility in rice (Sampath and Mohanty, 1954), efforts have been started to find out the possibility of utilizing hybrid vigor. Shinjyo and Omura (1996) developed first cytoplasmic genetic male sterile lines in cultivated rice by the substitution of the nuclear genes of Taichung 65 (*Japonica* variety) into the cytoplasm of Chinsura Boro II (*Indica* variety). IRRI, American and Indian scientists there after brought out further more precise the prospectus of exploiting hybrid rice succeeded by the substitution nuclear genes of widely cultivated *Japonica* varieties of USA, such as Calrose into the cytoplasm of BIRCO (PJ 279120) as well as *O. glaberrima* accessions. Likewise, Athwal and Virmani (1972) replaced Pankhari 203 in the background of TN-1 cytoplasm.

Even though a great number of research work has been done on various prospects of hybrid rice by different group of scientists, the hybrid technology could not succeed to develop commercial hybrid until Chinese scientists successfully developed a stable commercial cytoplasmic genetic male sterility fertility restorer system using the accidently found cytoplasm of *Oryza sativa f. spontanea* (WA) and brought out world's first commercial F_1 hybrid (Lin and Yuan, 1980). Hybrid rice term was successfully used in china from 1976 onwards when the Chinese scientists developed the technique of commercial exploitation of hybrid vigor by the use of Cytoplasmic Genetic Male Sterile System (CGMS). It was started in 1976 in China and thereafter in other rice growing countries.

Recognizing the potential of this technology, Indian Council of Agricultural Research launched a mission mode project on hybrid rice in 1989. This project was further elaborated by the monetary support from UNTP, MAHYCO Research Foundation and NATP. Keen efforts along with wholehearted support from funding agencies have made the country to enter into the era of hybrid rice. In India, even though the aim to develop and adapt hybrid rice technology started during 1970, the research works were widened and systemized only since 1989 with a mission mode project. With wholehearted research work, India commercialized half a dozen rice hybrids each from public and private sector within a short period of five years. During 1994, the first four rice hybrids *viz.*, APHR-1, APHR-2, MGR-1, KRH-1 were released in the country. Thereafter, two more hybrids *viz.*, CNRH-3 and DRRH-1 were also released. In different network centers, more than thousand experimental hybrids have been developed and evaluated. Either by the Central Rice Release committee or the State Variety Release Committees, thirty three hybrids were recommended for large scale cultivation, with the involvement of systematic research and private sector. Basmati rice hybrids were also developed and released by IARI, New Delhi.

Over the pure line check varieties, the released hybrids had an average yield advantage of 15-20 %. During the year 2005-06, a total of 17.11 m.ha area was under hybrid rice in some leading Asian rice growing countries (Kush, 2007). In India, more than 1.4 m.ha area was under hybrid rice cultivation during 2007-08 (Anon., 2008). In our country, hybrid rice is mostly cultivated in eastern Uttar Pradesh, Chhattisgarh, Uttar Pradesh, Orissa, Maharashtra, West Bengal, Andhra Pradesh, Karnataka, Tamil Nadu, Punjab, Haryana and Bihar. During the year 2011-12, the hybrid rice had occupied 1.3 m.ha and an additional production of rice (1.5 to 2.5 m. tons) was added to India's food basket through hybrid rice production technology.

2.1.1 Three line breeding

Rice being a strictly self pollinated crop needs an efficient pollen control system to build hybrids for commercial purpose. From the different approaches being followed to produce the hybrid seed, the use of Cytoplasmic Male Sterility system is the most relevantly convenient and is attracting the attention of breeders due to its simplicity and cost effectiveness of hybrid seed production. Development of potential CMS lines, maintainers, identification of restorers, and evaluation of parental lines as well as conversion of promising maintainer lines in to CMS lines forms an involving part of hybrid rice technology for an efficient rice breeding programme. The commercial exploitation of heterosis in rice has made possible, primarily, by use of Wild Abortive (WA) cytoplasmic and genetic male sterility-fertility restoration system (Lin and Yuan 1980, Virmani and Edwards, 1983).

Standardized cyto-sterile lines and legitimate restoration frameworks are required keeping in mind the end goal to market hybrid seeds (Virmani *et al*., 1997).

Yuan and Fu (1995) expounded all the stages that ought to be received to get male sterile lines, restorers and maintainers. As indicated by his investigations, hybrid rice could be delivered through three-line breeding framework, where one line have the genetic/cytoplasmic male sterility; the second line in charge of maintaining the sterility, and a third one which is utilized as the parent for the hybrid with the duty of reestablishing the fertility. Virmani *et al.* (2003) reported that cytoplasmic male sterility and the fertility restoration framework was utilized principally to create rice hybrids all through China since this innovation has served to be an alluring and contrasting option to break yield barriers and trigger rice production under different natural conditions.

2.2 HETEROSIS

The extension for the exploration of hybrid vigour in rice is relied upon the direction and magnitude of heterosis, biological attainability and the idea of action of genes. Genetic difference between the concerned parental lines decides the measure of heterosis for yield, agronomic and quality attributes. It helps in deciding genetic diversity and furthermore fills in as a manual for picking desirable parents (Virmani *et al.*, 1997).

The predominance of F_1s over the standard check is known as standard heterosis. Heterobeltiosis is signified as the increase or decrease of F_1 over the better parental lines. The measurement of these heterosis helps in the selection of potential cross combinations that can be utilized as a part of conventional breeding programmes which delivers an expansive range of variability in the segregating generations (Singh and Narayanan, 1990). A cross breed with the capability of being released for commercial farming ought to fundamentally beat the yield level of the best locally used variety and its CMS segment need to guarantee the hybrid seed production in a huge scale. For the genetic improvement in rice, this data should be used in different rice programs. Relevant writing accessible on heterosis in rice has been here surveyed and condensed.

In rice, heterosis was first reported by Jones (1926) and watched that some F_1 hybrids had a greater number of culms and gives higher yield than their particular parental lines. Several rice breeders also confirmed occurrence of heterosis in rice for yield and yield contributing characters (Virmani, 1994). In rice, a high value of heterosis has been reported by several other workers (Anandkumar and Rangaswamy, 1986; Manuel and Prasad, 1992 and Ram, 1992). Whereas lower degree of heterosis in rice was also registered by many researchers (Karunakaran,1968; Davis and Rutger 1976 and Khalique *et al.*, 1977). Virmani *et al.* (1982) and Mandal *et al.* (1990) reported that low degree of heterosis was due to lack of genetic divergence in the parents, though the expression of dominant gene action was operating in the inheritance pattern of the traits. There are several reports indicating the significance of heterosis for various agronomic characters in rice (Joshi. 2001).

In tropics, advance had been made during the previous two decades in the improvement and utilization of innovation of hybrid rice. Now and again this has been assessed (Mishra, 2003). IR58025A, IR62829A, IR68888A and IR68897A are among the principal IRRI-reared CMS lines that have been used to construct a few tropical commercial rice hybrids in India, Vietnam, Indonesia, Bangladesh and Philippines. International Rice Research Institute took plans to elevate innovation of hybrid rice in coordination with integrated national projects. During the later periods, CMS lines with better grain quality and a higher out crossing rate than IR58025A have been made. These lines additionally have the cytoplasmic diversity to get away from the danger of potential genetic vulnerability of hybrid rice to disease and insect as well as vulnerability related with the WA cytoplasm (Virmani and Kumar, 2004). Presently, hybrid rice is a reality in Asian nations like China, India, Vietnam, Philippines, Bangladesh, Indonesia and Sri Lanka and the extent of this innovation has been well demonstrated under tropical and in addition subtropical states of India (Mishra, 2009).

Peng *et al.* (2003) reported that the positive standard heterosis in grain yield in rice hybrids is identified with the increased dry matter production due to increased leaf area index, higher crop growth rate and harvest index, high spikelet number and increased thousand grain weight. Breeding systems in light of hybrid generation require a high state of heterosis and furthermore the Specific Combining Ability (SCA) of the crosses.

Swaminathan *et al.* (1972) and Virmani *et al.* (1981) have recommended that around 20-30 % standard heterosis might be thought to be adequate to beat the additional cost of hybrid seeds in self pollinated crops like rice. Sarawagi *et al.* (2000) enlisted significant and positive heterosis in a scope of 21.33 to 47.43 % for grain yield in rice. Significant yield increment in high heterotic mixtures was to a great extent ascribed to yield contributing traits like harvest index, biological yield, fertile spikelets panicle^{-1} and tillers plant^{-1}. In rice, Perera *et al.* (2001) and Naruzzaman *et al.* (2002) watched a high heterosis for grain yield and its component characteristics.

Anna (2002) assessed heterosis for some physiological qualities in rice. It was enlisted that hybrids demonstrating positive standard heterosis for harvest index indicated higher heterosis for yield. Additional study proposed that hybrid breeding programme be gone for assessing F_1 cross breeds with wide leaves and higher harvest index to get higher yield.

Joshi (2001) figured heterobeltiosis and standard heterosis in fourteen combination of crosses between the rice cultivars (landraces as well as enhanced) and three wild abortive male sterile parental lines. These crosses checked varieties in the declaration of heterobelitiosis and standard heterosis for yield and yield contributing traits. The most elevated heterosis among the yield parts was watched for panicle number plant^{-1} took after by spikelet number and panicle length.

Based on sterility of pollen and spikelet fertility, Joshi *et al.* (2003) grouped the test lines as restorers, partial restorers, maintainers and partial maintainers and reported five restorers, three incomplete restorers, two partial maintainers. They proposed that the maintainers so distinguished can be utilized to build up the hybrid seed while at the same time maintainers to keep up or potentially to grow new CMS lines since these are cultivars which are locally adjusted.

Heterosis at various levels was shown by Alam *et al.* (2004) in rice. They revealed that grain yield in a large portion of the crosses communicated a high significant positive measurement for the three levels of heterosis, on other hand, a negative heterosis was watched for the characters like days to panicle initiation, maturity in most of the crosses, days for complete flowering and flag leaf initiation.

Jin *et al.* (2005) revealed positive and additionally negative heterosis for ten characters. Heterosis was most significant for number of spikelets panicle^{-1} (average heterosis higher by 22.6 and 8.6 % than that in control and superior parents, respectively). The average estimation of heterosis over the superior parents for yield plant^{-1} was 9.5 %.

Bhandarkar *et al.* (2005) reported that the heterobeltiosis for grain yield went from 13.79 to 70.98 % greatest being in the cross INRC 140 x Madhuri A-9 and all the eight traverses their concerned parents for grain yield plant^{-1}.

Krishnaveni *et al.* (2005) directed an experiment with 23 crosses and discovered high significant and positive average heterosis and heterobeltiosis for grain yield in four crosses and the heterosis as well as heterobeltiosis ranged from - 60.2 to 297.9 % and - 65.1 to 235.2 % separately.

Bisne and Motiramani (2005) and Soni *et al.* (2006) recognized some cross blends made through line x tester mating configuration uncovering high standard heterosis in seed yield and its related attributes. Investigation of heterosis in various hybrids produced through line x tester mating design demonstrated hybrid vigour for yield and the vast majority of yield attributes (Gansekaran *et al.*, 2006; Saravanan *et al.*, 2006). Heterosis to the degree of 76.97 and 64.95 % over the mid parent and in addition better parent respectively was recorded for grain yield plant^{-1}.

Faiz *et al.* (2006) investigated F_1s created by crossing two CMS lines, IR69616A with IR70369A with two testers *viz.*, 60001 (a fine grain sweet-smelling advance line) and Basmati 385 (a mainstream Basmati variety). Two lines x two tester mating outline along with four genotypes and their F_1s were concentrated to appraise heterosis and combining ability impacts in yield and yield determining characters. Huge contrasts were noted in lines, testers and line x testers. Both the CMS lines lessened the plant tallness of their individual F_1 cross breeds. The highest positive heterobeltiosis was recorded for grain yield (41.83 %), number of productive tillers plant^{-1} (11.04 %) and number of filled grains panicle-1 (7.39 %) in the cross IR69616A with Basmati 385.

Malini *et al.* (2006) assessed 50 hybrids by pollinating five CMS lines and ten testers of differing origin in Line x Tester mating design in light of relative heterosis, heterobelitiosis and standard heterosis for seed yield and its contributing characters in rice. They noticed that a large number of the hybrids displayed significant negative heterobelitiosis and standard heterosis for days to flowering and maturity demonstrating the extent of exploiting heterosis for earliness. The relative heterosis for grain yield plant^{-1} extended from - 69.17 to 243.21 % combined with significant heterobelitiosis from - 75.71 to 219.75 %. The standard heterosis went from -73.71 to 129.16 % for grain yield plant^{-1}. The best hybrid was IR68885A x White ponni, which demonstrated a significant standard heterosis and heterobelitiosis for spikelets panicle^{-1}, grains panicle^{-1}, panicle length, straw yield and grain yield. Saravanan *et al.* (2006) considered heterosis in 28 different hybrids and found that the crosses between high x high and high x low gca parents showed the more prominent heterosis. The parents CRAC 2221-67 and Jaya were promising which demonstrated a higher heterosis for grain yield plant^{-1} and number of grains panicle^{-1}. They additionally announced that none of the crosses were at the same time top heterotic to all of the characteristics.

Singh *et al.* (2006) contemplated 36 crossovers for the measurement of heterosis and heterobeltiosis in ten characters and IR 580 25A x NDR 6054; PMS 1A x NDR 3026; IR 58025A x NDR 3013 and IR58025A x MDR 2022 were distinguished as the potential hybrids showing more than 60 % heterosis for grain yield.

As per Ushakumari *et al.* (2006) which contemplated forty two distinct hybrids of rice, revealed that the hybrid BP 176 (G) x ASD 18 had the most significant standard heterosis for single plant yield.

Rashid *et al.* (2007) from the investigation of 2 line x 3 tester mating design by utilizing five rice genotypes and 6 F_1s found that the tester was higher than that of interaction of line x tester all the traits. The most elevated significant heterosis (61.9%) was accounted for the hybrid of Super Basmati and DM-107-4 for yield plant^{-1}. The female Super Basmati, male DM-25 and DM-107-4 were seen to be great general combiners for all of the characters considered. The crosses between Basmati-370 x DM-25 and Super Basmati x DM-107-4 were seen as great specific combiners for the yield plant^{-1}. The cross mix Basmati 370 and EL- 30-2-1 was observed to be the promising specific combiner.

An examination by Fu *et al.* (2007) reported that days from sowing to panicle initiation, plant height and weight was keeping pace with that of the mid parent heterosis in all the hybrids. In a comparable report by Narasimhan *et al.* (2007) noticed that some cross combinations demonstrated exceedingly significant heterobeltiosis and standard heterosis for number of filled grains panicle^{-1}, biomass panicle^{-1} and grain yield plant^{-1}.

Torres and Geraldi (2007) considered rice hybrids utilizing incomplete diallel evaluation and noticed the significant mid-parent heterosis for all of the traits (plant tallness, tiller number, days to 50 % flowering, panicle length, grains panicle^{-1}, sterility and test weight). In this examination, the dominating effect's predominance direction was negative for days to 50% flowering and positive for the various other qualities contemplated.

Heterosis and heterobeltiosis in line x tester crosses of basmati rice extended from -21 to 60 % and -33 to 43 % respectively for flag leaf area, 17.9 to 53 %, -3.9 to 12.3 % and 3.3 to 32 % for plant height and -25.9 to 24 % for panicle density, -8.8 to 32 and -24 to -19.3 % for harvest index, 8 to 59 and 12.9 - 104.4 % for biological yield plant^{-1} and 12.5 to 95 and -7 to 66.4 % for yield plant^{-1} (Saleem and Mirza, 2008).

Venketesan *et al.* (2008) recorded the low estimates of heterotic values in rice for physical characters when contrasted with yield and yield components. A couple of hybrids were recognized that exhibited significant and positive heterosis over mid parent, better parent and standard check for the grain yield. Likewise they watched the lower assessments of heterosis values for physical characters when contrasted with yield and yield attributes. Nine hybrids showed positive and significant heterosis over mid parent, better parent and standard check for grain yield plant^{-1}, of which AD 95157 x IR 50, MDU 5 x IR 50, AD 95157 x ADT 43, MDU 5 x ADT 36, AD 95157 x ADT 36 and AD 95137 x ADT 36 were the toppers. Considering both yield and physical characters together, the crosses MDU 5 x IR 50, MDU 5 x ADT 36, AD 95157 x ADT 36, AD 95157 x ADT 43, AD 95157 x IR 50 and AD 95137 x ADT 36 could be deal with for having notable normal heterosis, mid parental heterosis and standard heterosis for yield and grain related characteristics.

Mehrajuddin (2009) watched the mean performance of hybrid rice for physiological characters. He distinguished that three promising hybrids which have the largest amount of heterosis for grain yield *viz.*, Pusa 3A x RR 564, Pusa 3A x HURFG-79 and Pusa 6A x RR 564. The majority of these hybrids beat the parental lines as far as Crop Growth Rate, Relative Growth Rate, and Leaf Area Index. Utilizing parental lines with high physiological productivity will guarantee positive heterosis in hybrids.

Neelam *et al.* (2009) crossed four CMS lines and nineteen testers in a line x tester mating design to work out heterosis over better parent and standard check for a few yield and yield crediting attributes in rice. Three crosses *i.e.,* IR 68897A x RPHR 111-3, IR 68897A x RPHR-641-1 and IR 79156A x EPLT-104 communicated the highest heterosis along with *per se* performance and SCA effects for traits like productive tillers plant^{-1}, number of filled grains panicle^{-1} and panicle length along with grain yield plant^{-1} over the standard check variety KRH-2.

Twenty rice hybrids made through a line x tester crossing program including five high yielding lines and four prevalent grain quality testers were evaluated for yield and quality characters by Roy *et.al.* (2009). They revealed that a higher extent of heterosis against all yield and quality attributes were not seen in a single hybrid combination but rather fluctuated starting with one cross then onto the next. The cross combinations, IET 5656 x Kalonunia, IET 8002 x Dudheswar, IET 5656 x Dudheswar and IR 62 x Samba Mahsuri were recognized by them for their unrivaled yield and grain quality characters.

Kumar *et al.* (2010) examined the scope of heterosis in an arrangement of 36 hybrids delivered from a 9 x 9 diallel mating design barring reciprocals including nine promising genotypes HPR1164, HPR2047, China 988, VL91– 1754, VL93–3613, VL93– 6052, IR57893-08, VL Dhan 221 and JD 8 of differing nature kept up in unadulterated frame. Out of 36 hybrids, twelve demonstrated significant heterosis for the traits concerned. All in all, the evaluations of heterosis esteems were low for quality attributes when contrasted with yield and morpho-physiological characteristics. They found that nine hybrids showed positive and significant heterosis over standard check yet seven over better guardians for grain yield plant^{-1}. Standard heterosis and heterobeltiosis for grain yield extended from 14 to 65 % and 22.6 to 65 %, respectively. The hybrid HPR 2047 x JD8 which recorded 65 % higher grain yield over both better parent and standard check was distinguished as the best hybrid to exploit hybrid vigour. Considering standard heterosis, they inferred that HPR 2047 x JD8 (65%), VL93– 3613 x IR 57893-08 (60 %) and VL93– 6052 x VL Dhan (54.9 %) were accounted for to be the three best performing cross breeds for grain yield plant^{-1}. The higher yield by these hybrids could be because of more panicle length, net assimilation rate, leaf area index, dry matter, harvest index and test grain weight. These crosses might be utilized in future breeding programs for the advancement of high yielding hybrids and varieties. The hybrid combinations VL91– 1754 x VL93– 3613, VL91– 1754 xJD8 and VL933613 x JD8 recorded desirable heterosis over both better parent and in addition the standard check for grain quality and grain yield plant^{-1}.

Significant heterotic values over better parent and standard checks of appropriate magnitude was observed for grain yield and yield component traits besides for early maturity by Najeeb *et al.* (2011).

Tiwari *et al.* (2011) assessed three CMS lines and twenty best performing restorers in line × tester mating design to discover best heterotic blend and proposed that the majority of them traverses better parent or standard variety for grain yield and furthermore indicated significant heterosis for the characters like fertile spikelets and number of spikelets panicle^{-1}. The crosses additionally had around eighty per cent pollen viability. A few crosses communicated more than 50 % of heterosis alongwith significant desirable SCA effects and subsequently were viewed as valuable for commercial exploitation.

Krishna (2011) directed a field explore different avenues regarding twenty eight hybrids made by crossing eight parents impervious to gall midge, BPH and blast disease in 8 x 8 diallel model. The ensured hybrids identified for further use in hybrid rice program were WGL 32100 x White ponni, JGL 1881 x White ponni and JGL 3844 x MTU 4870. The genotypes *viz.*, WGL 32100, JGL 1881 and White ponni were helpful for change into male sterile lines or for the recognizable proof of restorer lines since they are resistant to gall midge. The mean, standard heterosis and heterobeltiosis were assessed for yield along with quality characters. A high measure of heterosis existed just for the yield components *viz.*, panicle weight, thousand grain weight and productive tillers plant^{-1} while, it was low for the quality attributes *viz.*, kernel length and length by breadth ratio.

It is critical to know the degree and direction of hybrid vigour for its business use. Heterobeltiosis and standard heterosis were contemplated in 14 crosses between rice (*Oryza sativa* L.) cultivars (improved and in addition landraces) and three wild sterile male sterile parents by Joshi (2001). These crosses stamped variation in the expression of heterobeltiosis and standard heterosis for yield along with yield components. Grain yield showed significant heterobeltiosis and standard heterosis in the five crosses. Heterobeltiosis ranged from – 55 to 139%. While at the same time standard heterosis ranged from – 11 to 369 %. Highest heterotic effect among the yield components was for panicle number plant^{-1} took after by spikelet number and panicle length. He inferred that with proper decision of the parental lines, it is conceivable to create F_1 rice hybrids having outstanding yield prevalence over the current best-inbred lines.

Dwivedi and Pandey (2012) assessed forty five hybrid rice along with six semi dwarf, short to mid-early duration and high yielding *Indica* (Pant Dhan 4, Sarjoo 52, Govind, Manhar, Pant Dhan 12 and Narendra 359) along with four tropical *Japonicas* cultivars (BSI16, B4116 , BSI10, and B4122) which are having wide similarity gene(s), to examine gene action and heterosis for grain yield and associated characteristics. He directed the examination in Randomized Complete Block Design and information gathered on different characters were investigated for heterosis and combining ability. Expressions of characters were found to be controlled by additive and non additive gene actions. The proportion of General Combining Ability (GCA) to Specific Combining Ability (SCA) variance noted greater relevance of non-additive gene action administering yield and related attributes. Parent Sarjoo 52 and B4122 were observed to be the best general combiner for maximum characters, including grain yield plant^{-1}. The crosses B4122 x Manhar, B4116 x Sarjoo 52, BSI10 x Narendra 359, BSI10 x Pant Dhan 12, and B4122 x Govind enlisted the most astounding SCA effect for yield plant^{-1}. They noticed that heterosis over mid parent, better parent and standard variety went between - 54 to 169, - 58 to 150 and - 65 to 146%, separately. Inter specific hybrids displayed more heterobelitiosis and economic heterosis.

Basmati rice varieties are popular for their pleasant aroma and great grain and cooking quality attributes. These varieties are poor yielders. The yield capability of basmati varieties can be enhanced by the exploration of heterosis as likewise reflected by the colossal achievement of PRH 10. Remembering this, the essentialness of heterosis, twenty eight F_1s barring reciprocals were created utilizing 8x8 diallel mating design by Kumar *et al.* (2012). Mid parent, better parent and economic heterosis were recorded for yield and its components and found that crosses of Pant Sugandh Dhan 15 x UPR 3003-11-1-1, Pant Sugandh Dhan 15 x UPR 2845-6-3-1 and Pant Sugandh Dhan17 x UPR 3003-11-1-1 had highest economic heterosis for grain yield (309, 244 and 256 %), biological yield (158, 150 and 124.6 %) and for harvest index (58.6, 37.8 and 58.4 %).

Jarwar *et al.* (2012) examined heterotic performance of twenty one F_1 hybrids and their ten parents in a Randomized Complete Block Design with three replications in two distinct conditions. Huge contrasts were seen among parents, hybrids and parents for the greater part of the agronomic characteristics of hybrids in both these situations. Genotype x Environment interaction was observed to be significant in a large portion of the attributes considered. These distinctions demonstrated the presence of variability and heterosis for these characteristics. Lines *viz.*, Rataria, Sugdasi and LR2; testers *viz.*, Pandan and Basmati 370 had the most astounding qualities under the two conditions. Then again, the crossovers Bengalo x Pandan, Sugdasi x Pandan and DR65 x Vertin reported the most significant standard heterotic values under wetland and upland conditions. They recorded that heterosis breeding might be used to enhance yield and different attributes with dominant gene action. Significant negative heterosis was likewise seen in days to fifty % flowering, days to maturity and plant height which was acceptable for growing early maturing and semi tall varieties.

Patil *et al.* (2012) line x tester analysis utilizing a set of four females (lines) and ten males (testers) which was done to appraise the heterobeltiosis for yield and yield attributes in rice (*Oryza sativa* L.). Significantly high extent of heterobeltiosis in desirable direction was watched for grain yield plant^{-1}, grains panicle^{-1}, panicles plant^{-1}, panicle length, days to fifty percent flowering, L/B proportion and 1000 grain weight. A many as sixteen traverse their respective better parental value for grain yield per plant. Crosses Sathi 34-36/GR-6, Sathi 34-36/ Lal kada, along with the cross GR-5/GR-6 were observed to be most heterotic hybrid combinations for grain yield plant^{-1}. Parallel increment in panicles plant^{-1}, grains panicle^{-1} and thousand grain weight with constructive outcomes towards higher grain yield was likewise detailed by them.

2.3 GRAIN QUALITY PARAMETERS

After yield, rice quality is considered as the 2nd most important trait in rice breeding programs, and sometimes the most important and the most valuable trait. Better quality rice gives better returns to the farmer therefore, rice lines with better yield as well as supreme quality is very important while breeding in rice.

Lyon *et al.* (2000) claimed that rice texture is a key pointer of grain quality parameters of rice as it influences the acceptance of cooked rice by the shoppers.

Khatun *et al.* (2003) stated that prime rice eating nations have the preference towards the varieties that elongate considerably after cooking. Azabagaoglum *et al.* (2009) and Musa *et al.* (2011) disclosed that purchasers' inclination indicates variety in light of the sort of rice and their place of root. The central point behind contrasts in cooking conduct of rice can be considered as due to the varietal and cultivar differences (Ashogbon and Akintayo, 2012). Hence for high yielding variety approval, rice breeder, along with yield should give preference to quality parameters which enhance the economic importance of rice.

As indicated by Huang *et al.* (1998) and Wan *et al.* (2004), grain quality is a vital attribute and comes after yield and is extremely perplexing attribute and includes numerous imperative attributes, for example, processing quality, grain estimate, shape, appearance and other cooking qualities. Paramita *et al.* (2002) and Hossain *et al.* (2009) presumed that rice is the main cereal grain consumed mainly as whole grain and quality considerations in rice are significantly more critical than in some other food crop.

According to Sobharani *et al.* (2008), the characters that embed significant impacts on the eating and in addition cooking characteristics are related with the physico-compound properties of rice grains like amylose content, gelatinization temperature, gel consistency, fragrance and grain length after cooking.

2.3.1 Optimum cooking time

Different physicochemical attributes deciding the cooking behavior and the texture of cooked rice affects rice grain quality. They revealed that Cooked Grain Length (CGL) is one of the significant cooking quality properties. To decide endorsement of a rice variety, kernel shape and visual appearance of rice when cooking is critical. The quality during cooking and handling , which can be seen in terms of grain lengthening at the time of cooking, amylose content, processing and preparing frameworks likewise add to the financial estimation of rice (Bocevska *et al.*, 2009 and Moongngarm *et al.*, 2010).

Mohapathra and Bal (2006) revealed that rice variety, conditions during drying and storage, rice (rough) moisture content, amylose content, kind of starch, level of processing, water/rice proportion, techniques for cooking, pre-cooking and post-cooking preparing are the impacting parts for the cooking and textural attributes of rice. Saleh and Meullenet (2007) complimented that more drawn out cooking length brings about higher moisture take-up of rice, giving gentler cooked rice. Sugeetha (2010) communicated the most elevated cooking time of 48.16 minutes in MO-87-5 and least of 32.33 minutes in MO-2. Lakshmi (2011) noted down a cooking time of 44.67 minutes in parboiled Jyothi variety . Sathyan (2012) revealed that crude seeds of the variety Jyothi have a cooking time of 29.33 minutes. In an investigation done by Thomas *et al.* (2013), the longest cooking time of 31.67 minutes was taken by dark colored rice than white rice varieties and they found that texture of cooked rice is influenced by milling and duration of cooking. Lightly milled rice samples reported lower moisture take-up during cooking, hence giving harder cooked rice.

2.3.2 Volume expansion

Sathyan (2012) quoted that Jyothi rice have a grain weight of 25.67 g and grain volume of 25.8 mm^3. According to Lakshmi (2011), parboiled Jyothi rice grain has weight of 26.56 g and grain volume of 3 mm^3.

2.3.3 Kernel length (mm)

For quality, the rice grain can be arranged into long grain, medium grain and short grain (Kwarteng *et al.*, 2003).

2.3.4 Kernel length by breadth ratio

In rice, main factor responsible for the grain appearance are grain shape and chalkiness ratio (the ratio between opaque and translucent grains). Breeders give more attention to the size of the grain and shape in developing the new rice varieties (Adair *et al.*, 1966). According to Slaton *et al.* (2001) rice varieties are classified as short, medium or long grains by rough kernel dimension ratio. In 2005 Armstrong *et al.* reported that rice buyers, millers and consumers judge the quality and the uniformity of kernel size and shape as well as the appearance and overall size-shape relationship.

In some studies conducted on new rice type genotypes, it was reported that kernel length/width ratio of cooked rice varied from 2.0 to 3.9 and 2.4 to 5.1 respectively (Sandeep and Zaman, 2003; Hossain *et al.*, 2009 and Danbaba *et al.*, 2011). Sugeetha (2010) conducted a study among eight pre-release rice cultures of KAU for various quality attributes and observed that the mean length of grain was found to be highest for MO8-20-KR (6.88 mm) and lowest for MO-87-5 (5.60 mm). The width was found to be highest for the variety OM-3 (2.73) and lowest for MO-95-1 (2.29) variety. Lakshmi (2011) recorded that parboiled grains of Jyothi rice variety have grain length of 6.70 mm, grain width of 2.50 mm and length and breadth ratio of 2.66 and is of the class long medium. Sathyan (2012) noted grain length of 6.65 mm, grain width of 2.20 mm and length and breadth ratio of 3.02 in the grain of Jyothi variety which specifies the grain as long slender. Thomas *et al.* (2013) wrote down that highest length and breadth proportion was noted for the white (local) rice (3.8) while the lowest ratio was recorded for brown rice (2.1).

2.3.5 Head rice recovery in milling (%)

In 2003, Septiningsih concluded that chalky grains are more likely to break during milling because they are not as hard as the translucent ones. According to Alko *et al.* (2004), head rice is an essential character for milled rice and main factor in determining rice market value and shape of the grain. Grain quality characteristics like milling per cent, appearance of grain, nutritional components and cooking quality are very important in rice (Babu *et al.* 2012).

Nandini (1995) conducted a study among sixty rice varieties; thousand grain weight of husked rice was found to be higher in hybrid derivatives of rice. Reshmi and Vyttila-3 also reported a higher head rice yield in traditional varieties. The highest rice yield was observed for the varieties Chuvannari and Thavalakannan followed by Vyttila-3. According to Singh *et al.* (2003), the thousand kernel weight of translucent grain was significantly lower than chalky grains obtained from different varieties. The highest value for thousand grain weight for raw rice was recorded for the variety M-108-262-1 (23.34 g) (Sugeetha, 2010). According to Lakshmi (2011) and Sathyan (2012), a head rice recovery of 62.16 % and 33.66 % was observed in parboiled as well as raw rice of Jyothi.

The physiochemical properties of six different rice varieties from Malaysia were studied by Thomas *et al.* (2013) and it was observed that glutinous rice had the highest thousand kernel weight (19.4g). This was followed by Bario rice (19.2 g) and brown rice (18.7 g). For white rice variety, the lowest thousand kernel weight was observed (16.9 g).

2.3.6 Amylose content

Past results during the prior investigations pokes that cooking quality is straightforwardly identified with the physical and in addition the chemical attributes of the endosperm starch like Alkali Spreading Value (ASV), Amylose Content (AC) and Gel Consistency (GC) (Little *et al.*, 1958; Juliano, 1980; Webb, 1980; Unnevehr *et al.*, 1992; and Tan *et al.*, 1999).

According to Del *et al.* (1968), chalky grains express low density of starch granules compared with translucent ones.

According to Hamaker and Griffin (1990), cooking characteristics along with eating characteristics of rice is directly connected with the amylose content. Nandini (1995) revealed that hybrid derivatives had higher and traditional rice varieties had lower amylose content. Lii *et al.* (1996) communicated the possibility that amylose content is considered as the most critical trademark for finishing up cooking and preparing attributes of rice. Cooking quality of rice is directly connected with the physical and chemical characteristics of the starch in the endosperm and amylose as well as amylopectin ratio (Tan *et al.* 1999). According to Perdon (1999), cooked rice with low amylose content is delicate and sticky, while at the same time rice with high amylose content is firm and fluffy. As indicated by Hossain *et al.* (2009), in *Japonica* rice eating nations, low amylose and short grain is favored and in *Indica* rice devouring nations, long grain with intermediate amylose and gelatinization temperature is generally favored.

In 1996, Delwiche noticed that amylose content is connected straightforwardly to the water assimilation, volume extension, softness and detachability of cooked rice. According to Slattery *et al.* (2000), the relative amount of amylose and amylopectin affects the unique physical and chemical properties of starch. Paramita *et al.* (2002) graphed that amylose content, gelatinization temperature and also gel consistency can profoundly impact cooking and eating characteristics of rice.

Aliwati (2003) narrated that rice varieties with a higher amylose content are hard and dry in texture compared with rice with lower amylose content. Kishine *et al.* (2008) remarked that Nerica rice varieties of Africa had high amylose content. "Njavara" and "Jyothi" have been observed to have similar amylose content of 23% (Deepa *et al.*, 2008). Sathyan (2012) stated that germinated Jyothi rice have amylose content of 24.5 %.

According to Hamaker and Griffin (1990), cooking, eating qualities of rice is directly associated with the amylose content. The lowest amylose content of 3.36 % was found in brown rice followed by black rice (5.11%) with the highest (27.71%) in white rice (Thomas *et al.*, 2013). Sathyan (2012) stated that germinated Jyothi rice have an amylose content of 24.5 %.

2.3.7 Gelatinization temperature

Rice texture of a variety is influenced by characteristics, for example, amylose percentage and gelatinization temperature, processing elements and technique for cooking. Kaur *et al.* (1991) affirmed that cooking time is specifically influenced by the gelatinization temperature of starch and protein.

Gelatinization temperature influences the cooking behavior (Bandayopathyay and Roy 1992). Lakshmi (2011) and Sathyan (2012) recorded a gel length of 37.66 mm and 48.10 mm in parboiled and raw rice variety Jyothi. Sabouri *et al.* (2012) recorded that gelatinization temperature is associated with amylose content and also rice varieties with high gelatinization temperature generally have low amylose content. Oko *et al.* (2012) got diverse rice varieties of Nigeria and uncovered that Faro 15 (I) and E4077 were observed to be harder than the others. Rice genotypes with a harder gel consistency solidify quicker than those with a delicate gel consistency when cooked. The creator additionally uncovered that the rice with delicate gel consistency cook more tender and stay delicate even after cooling. High degree of variability in a populace gives a chance to the determination of assortments having attractive characters (Haider, 2017).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment on "Evaluation of CMS based rice hybrids developed from rice varieties of Kerala identified as restorers" was conducted at College of Agriculture, Vellayani and Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram during *Virippu* and *Mundakan* of 2017-18 to evaluate CMS based rice hybrids developed from rice varieties of Kerala as restorers for heterosis for grain quality and yield. The materials used and methods adopted are briefly explained in this chapter.

3.1 HYBRID SEED PRODUCTION

The details of the parents and the male sterile line used in the study is given in the Table 1 and the images related are given in Plate 1. The parents were grown during May to June 2017 and the crossing programme was undertaken during July to August, 2017 (*Virippu*, 2017).

3.1.1 Staggered sowing

Two CMS lines *viz*., CRMS31A and CRMS32A were crossed with identified restorers and the restorers and the CMS lines were sown in staggered dates.

At the time of flowering, female plants were taken from the field and planted in pots. Restorers were sown in three staggered dates. *i.e.*, one at 10 days before the sowing date of CMS lines, the other 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. 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 amount of viable seeds for next season was taken for hybrid evaluation.

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)	RRS, Pattambi, KAU	Short duration, Red Kerneled
	Mattatriveni (PTB 45)	RRS, Pattambi, KAU	Short duration, Red kernelled
	Swarnaprabha(PTB43)	RRS, Pattambi, KAU	Short duration, white kernelled
	Aiswarya(PTB52)	RRS Pattambi KAU	Medium duration, Red kernelled
	Jayathi (PTB 46)	RRS,Pattambi,KAU	Medium duration, White kernelled
	Remya (MO 10)	RRS,Moncompu,KAU	Medium duration, Red kerneled
	Kanakom (MO 11)	RRS,Moncompu,KAU	Medium duration, Red kernelled
	Neeraja(PTB 47)	RRS, Pattambi,KAU	Long duration, white kernelled.
Check varieties	Uma (MO 16)	RRS,Moncompu,KAU	Medium duration, Red kernelled
	Kanchana (PTB 50)	RSS,Pattambi,KAU	Short duration, Red kernelled

3.1.2 Hybridization Technique

The female plants were uprooted from the field at the time of 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 program. Pollen sterility test was used to confirm this. Clipping method was utilized for emasculating the seed parents When the upper florets exert anthers, spikelets were cut $1/3^{rd}$ from the tip of the rice floret to encourage out crossing as well as covered with butter paper cover after removing anthers. Panicles were taken from the male parent from field at the time of blossoming between 9 am to 10:30 am. These panicles of male parent were made to absorb water and kept under the warmth and light of incandescent lamb (60 watt) (Plate.1.b). After the entire exertion of anthers from the spikelets, the pollen was dusted upon the female parent kept inside the crossing chamber. The pollinated panicles were covered with butter paper cover and kept in dry environment. The seeds started to emerge after 3-5 days (Plate. 1.d). 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 away and marked.

3.1.2.1 Pollen sterility test

Sterility of pollen was checked on each plant of CMS lines before hybridization in order to prevent the contamination due to selfed seeds. This was detected by staining of pollen grains in 1% potassium iodide-iodine (I-KI) solution (Chaudhary *et al.,* 1981). At rice heading, around ten spikelets from each female plant were gathered early in the day before their blossoming and retained in 70% ethanol. All the anthers from six spikelets were taken out with the assistance of forceps and kept in the stain and observed under compound microscope (10x). The average of three random fields were recorded.

Plate 1: Hybrid Seed Production

a. Stagged sown restorers with CMS lines

b. Panicles of restorer kept under incandescent bulb for anther exertion

c. CMS lines after hybridization

d. Seed set after clipping method of hybridization

3.2 HYBRID EVALUATION

3.2.1 Design and layout

Design	: RBD
Treatments	: 8
Replication	: 3
Plot size (Gross)	: 3 m x 3 m
Spacing	: 20 cm x 15 cm
Season	: *Mundakan* 2017- 18

Hybrid evaluation was conducted during October to February 2017-2018 *(Mundakan)* at IFSRS, Karamana located geographically at 11° N latitude 77°E longitude in an altitude of 5 m above mean sea level.

The seeds were germinated in petri plates with water soaked tissue paper inside. The germinated hybrid seeds along with two checks were planted in dapong trays of 60 cm x 30 cm filled with field soil in 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 appraise the heterosis. Twenty one days old seedlings were transplanted to mainfield at a spacing of 20 cm x 15 cm. A plot of 3 m x 3 m were made with bunds of width 30 cm on all the four sides (Plate 2).

3.2.2 Agronomic practices

Farm yard manure @ 5 t ha $^{-1}$ was added to all the plots uniformly. The fertilizer recommendation of 70 kg N, 35 kg P_2O_5 and 35 kg K_2O ha^{-1} followed for short duration varieties, 90 kg N, 45 kg P_2O_5 and 45 kg K_2O ha^{-1} for medium duration varieties(KAU POP, 2016) and 150 kg N, 75 kg P_2O_5 and 75 kg K_2O ha^{-1} for all the

Plate 2. Field view of evaluation of hybrids

a. Layout of field

b. General field view

hybrids (Mohan *et al.,* 2014). Irrigation and drainage channels were also provided. Thinning and gap filling were done at 30 DAS to maintain uniform population at one seedling hill^{-1}. One hand weeding was carried out at 30 DAS and another on 60 DAS. Prophylatic sprays of FAME 1ml/10L for leaf roller and stem borer, K cyclin (2g/L) for bacterial leaf blight and Fenwal 1ml/L for rice bug was done.

The crop was harvested during February, 2018. Plants in one border row on all 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 plot^{-1}.

Table 2. Treatment names

Treatment names	Variety / Hybrid
C_1	Uma
C_2	Kanchana
H1	CRMS31A x Jayathi
H2	CRMS31A x Kanakom
H3	CRMS31A x Remya
H4	CRMS32A x Annapoorna
H5	CRMS32A x Kanakom
H6	CRMS32A x Mattatriveni

3.2.3 Observations

3.2.3.1 Observations on morphological characters

All the observations were recorded in five observational plants plot^{-1} selected randomly.

3.2.3.1.1 Plant Height (cm)

Height of plant was measured in centimeter from base of the stem to tip of the top most leaf at 100 DAS.

3.2.3.1.2 Number of Productive Tillers

The number of productive tillers was recorded from observational plants of each plot at harvest and mean values were calculated accordingly.

3.2.3.1.3 Days to Flowering

Number of days taken to flower by the population in a plot from sowing date was recorded.

3.2.3.1.4 Panicle Length (cm)

Panicle length was measured in centimeter from the point of scar on the base of panicle from observational plants.

3.2.3.1.5 ***Pollen Fertility***

Pollen fertility of the treatments was estimated by staining the pollen grains in 1% potassium iodide-iodine (IKI) Solution (Dalmacio *et al.*, 1995, Virmani *et al.*, 1997, Chaudhary *et al.*, 1981, Sohu and Phul, 1995). At heading, about 15 spikelets from each plot were acquired (morning just before their blooming) and fixed in 70% alcohol. All the anthers from six spikelets were taken out and placed in the stain Using a needle, pollen grains were released. After removing the surrounding debris, these were observed under microscope (10x). The pollen grains present in 3 random microscopic fields were counted; classified based on their shape, size and extent of staining (Virmani *et al.*, 1997, Chaudhary *et al.*, 1981) according to the Table 3.

Table 3. Categories of pollen shape and staining behavior classification

Pollen categories	Shape, staining behavior	Classification
Unstained withered sterile (UWS)	Withered, undeveloped, Unstained	Sterile
Unstained spherical sterile (USS)	Spherical , smaller, unstained	Sterile
Stained round sterile (SRS)	Round, small, lightly/ incompletely stained, rough surface	Sterile
Stained round fertile (SRF)	Round, large, darkly stained, smooth surface	Fertile

3.2.3.1.6 Number of Spikelets Panicle^{-1}

The spikelets from each panicle was removed and counted from the five sample plants in each plot and the mean value was worked out.

3.2.3.1.7 Days to Maturity

Days from germination to harvest was recorded for each plot

3.2.3.1.8 Number of Filled Grains Panicle $^{-1}$

From the five observational plants, the number of filled grains per panicle was counted and average value was recorded.

3.2.3.1.9 Length- Breadth Ratio of the Grain

15 grains were selected randomly from each observational plant, measured length and breadth and its ratio was calculated.

3.2.3.1.10 1000 Grain Weight(g)

From the each plot, thousand grains were separated from clean produce and mean weight was expressed in gram.

3.2.3.1.11 Grain Yield (g) Plant^{-1}

From each plot the grains of five observational plants were harvested individually. Its grain weight was recorded after sun drying to a moisture of 14 percentage.

3.2.3.1.12 Yield Plot^{-1}(kg)

The grains were harvested from each net plot area separately and dried in sun to a moisture content of 14 per cent and its weight was recorded and expressed in kilogram.

3.2.3.2 Cooking Qualities

3.2.3.2.1 Optimum Cooking Time

Plot wise harvested grain samples were analyzed for optimum cooking time after milling was determined. (Hirranniah *et al.*, 2001). Ten gram sample of whole healthy milled grain was taken in a 250 ml vessel containing 150 ml slow boiling water over the electric stove (1.5 kw). Glass plate opaque core method was used to determine cooking time for that few grains were taken periodically and pressed between two glass slides until no white core seen.

3.2.3.2.2 Volume Expansion

Water displacement method was used to find the volume of initial uncooked rice. Until the optimum cooking time, the milled rice was cooked in a boiling water bath. Cooked rice was then blotted to free water avoiding the loss of solid.

Displacement method was again used to measure the volume of cooked rice (Juliano, 1971).

Volume expansion= Volume of cooked rice/ Volume of raw rice

3.2.3.3 Grain Quality

3.2.3.3.1 Kernel Length (mm)

Kernel length was recorded using Dial Vernier Calipers (Khan *et al.*, 2003). For that 10 whole grains were selected randomly from each replication. According to SES, IRRI (2002), rice grains are classified into four based on their length.

Extra long- >7.50 mm

Long – 6.61- 7.50 mm

Medium- 5.51- 6.60 mm

Short- <5.50 mm

3.2.3.3.2 Kernel Breadth (mm)

Breadth was also measured using Dial Vernier Calipers (Khan *et al.*, 2003).

3.2.3.3.3 Kernel Length by Breadth Ratio

This observation was used to determine the shape of grains as

Slender-> 3 mm

Medium- 2.10 to 3 mm

Bold- 1.10- 2 mm

Round- < 1mm (SES, IRRI, 2002)

3.2.3.3.4 Kernel Colour

Colour of the kernel was observed and classified as red and white.

3.2.3.4 Head Rice Recovery in Milling (%)

Rice grains after drying, hulling and milling were separated as whole and broken grains manually using conventional method. Head rice (full grains and ¾ grains) were separated and weighed (SES, IRRI, 2002) and the percentage of head rice recovery was calculated as,

$$\text{Head Rice Recovery} = \frac{Weight\ of\ whole\ polished\ grain}{Weight\ of\ paddy} \times 100$$

3.2.3.5 Chemical Characterization

3.2.3.5.1 Amylose Content (%)

100 mg of powdered rice grain was weighed and 1 ml of distilled ethanol and 9 ml of 1N NaOH were added. It was boiled for 10 minutes in water bath. Using distilled water, the volume was made up to 100 ml. In 5 ml of sample suspension, added 1 ml of acetic acid (57.75 ml /L), 50 ml of distilled water along with 1.5 ml of Iodine solution (2% potassium iodide containing 0.2% w/v iodine) were added. Made up the volume to 100 ml. and kept it for 20 minutes. OD values at 620 nm were measured. For calibration, NaOH solution was used as blank solution. Standard graph using sigma potato amylase was used to calculate per cent amylose content of samples (Perez and Juliano, 1978). The amylose content was classified as 1-2% (Waxy), 2-9% (Very low), 9-20% (Low), 20-25% (Intermediate) and 25- 33% (High).

3.2.3.5.2 Gelatinization Temperature

Alkali digestion test was used to determine gelatinization temperature. A duplicate set of six whole-milled kernels (without cracks) was selected and placed in a plastic box of dimension 5×5×2.5 cm. 10 ml of 1.7% KOH solution(0.3035 M) was added. Enough space was provided between samples kernels that allowed spreading. The boxes were then covered and were incubated for 23 h in an oven

(30°C). The starchy endosperm was visually rated based on a seven-point numerical spreading scale (as per SES). In accordance with the Alkali Spreading Value score, gelatinization temperature of rice grains was classified into four groups *viz*., high (1–2), high-intermediate (3), intermediate (4–5) and low (6–7) .The scoring was done as follows,

1. Not affected kernel
2. Swollen kernel
3. Swollen kernel, incomplete & narrow collar
4. Swollen kernel, complete & wide collar
5. Split/ segmented kernel, complete & wide collar
6. Dispersed kernel, merging with collar
7. All the kernels dispersed & intermingled

3.2.3.6 Scoring of pest and diseases (if any)

No major pest and disease were found to infest the crop beyond the economic threshold level demanding control measures. Since the insect and disease attack were below the economic threshold level, scoring was not done.

3.2.4 Statistical Analysis

3.2.4.1 ***Analysis of Variance (ANOVA)***

i. Randomized Block Design (RBD)

Using the following ANOVA table, RBD analysis was performed to analyze the characters.

Table 4. ANOVA for Randomized Block Design

Source	d.f	SS	MSS	F
Treatments	(v-1)	$\frac{\sum Ti2}{r} -$ $C.F$(SST)	MST=$\frac{SST}{v-1}$	$\frac{MST}{MSE} \approx F_{v-1}$
Replications	(r-1)	$\frac{\sum Yj2}{v} -$ $C.F$(SSR)	MSR=$\frac{SSB}{r-1}$	$\frac{MSR}{MSE}$
Error	(v-1) (r-1)	SSE=TSS-SST-SSB	MSE=$\frac{SSE}{(v-1)(r-1)}$	
Total	(vr-1)	$\sum Y_{ij}^2$-CF		

Where,

v = Number of treatments

r = Number of replications

T_i = i^{th} treatment

Y_j= j^{th} replication

C. F= Correction Factor

SST= Treatment Sum of Squares

SSE = Error Sum of Squares

SST= Total Sum of Squares

MST=Mean Sum of Treatments

MSR=Mean Sum of Replications

MSE=Mean Sum of Error

The null hypothesis was rejected at α level of significance if the calculated F ratio corresponding to treatment and replication be greater than the corresponding table value with corresponding degrees of freedom at the same level of significance.

When the test is not significant, there exists no significant difference among the treatments with respect to the particular traits under consideration: all treatments are statistically on par.

If the treatments are significantly different, different CD may be used for comparison between treatments

It is given as,

$$CD_{(0.05)} = t_{(v-1)(r-1)} \times \sqrt{\frac{2MSE}{r}}$$

3.2.4.2 *Estimation of Genetic Variability Parameters*

The variability for different traits among various genotypes are calculated as per described below.

3.2.4.2.1. Genotypic and Phenotypic Variance

Burton and Devane (1953) had given the formula to calculate genotypic and phenotypic components of variance.

$$\text{Genotypic variance } (V_g) = \frac{MSS \text{ due to genotypes} - MSS \text{ due to error}}{r}$$

$$\text{Phenotypic variance } (V_p) = \text{Genotypic variance } (V_g) + \text{Error variance } (V_e)$$

3.2.4.2.2. *Co-efficient of Variability* (Burton and De Vane, 1953).

$$\text{Phenotypic Coefficient of Variability (PCV\%)} = \frac{\sqrt{(Phenotypic\ \ variance)}}{Grand\ mean} \times 100$$

Genotypic Coefficient of Variability (GCV%) = $\frac{\sqrt{(Genotypic\ \ variance)}}{Grand\ mean}$ x 100

Classification of variation range (Sivasubramanyan and Menon,1973).

< 10%	Low
10-20%	Moderate
>20%	High

3.2.4.2.3. ***Heritability in Broad Sense, (h^2)***

Broad sense heritability was calculated as per Lush (1949) and Allard (1960).

$$h^2 = \frac{Genotypic\ variance}{Phenotypic\ variance}$$

Here is the categorization for heritability estimates (As per Johnson *et al*, 1955)

<30% - Low; 30-60% - Moderate; >60% - High

3.2.4.2.4. Genetic Advance (GA)

$GA = h^2_{bs} \times \sigma_p \times k$

(Johnson *et al*., 1955).

Where,

h^2_{bs} = Broad sense heritability

σ_p= Phenotypic standard deviation of the character

k = Standard selection differential (2.06 at 5% selection intensity).

Also,

$$\text{GA as per cent of mean} = \frac{GA}{Grand\ mean} \times 100$$

0-10 % - Low

10.1- 20 % - Moderate

20.1% - High

3.2.4.3 Estimation of Heterosis

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

$$\text{Per cent heterosis over Better parent (BP)} = \frac{F1-BP}{BP} \times 100$$

$$\text{Per cent heterosis over standard check} = \frac{F1-SC}{SC} \times 100$$

F1 = Mean performance of F_1 hybrid

BP= Mean performance of better parent

SC= Mean performance of standard check

For better parent value (BP) for each trait, superior value exhibited by the restorer of cross was taken for computation of heterosis.

The test of significance of calculated F value was done by referring the table F value at 5 per cent and 1 per cent probability.

The standard error (SE), critical difference (CD) and standard error of mean (SEm) for comparison of means was calculated as follows.

SE= $\frac{2XMSE}{r}$

CD (at 5%)= SE x 't' value at error degrees of freedom and 5% level of significance

CD (at 1%) = SE x 't' value at error degrees of freedom and 1% level of significance

3.2.4.3.1. Standard Error of Estimates and Test for Statistical Significance of Heterosis

To assess the standard error of estimates of heterosis, mean squares due to error from RBD ANOVA was considered.

SE (BP) = $\frac{2XMSE}{r}$ (For testing heterosis over better parent)

SE (SC) = $\frac{2XMSE}{r}$ (for testing heterosis over standard check)

't' value for BP heterosis = $\frac{F1-BP}{SE\ (BP)}$

't' value for SH heterosis = $\frac{F1-SC}{SE\ (SC)}$

The calculated t value was compared to table 't' value at (r-1) (t-1) degrees of freedom. Where,

F1 =Mean of F_1

r = Number of replications in RBD

SC = Mean of standard check

SH = Standard heterosis

SE = Standard error

BP = Better parent Mean

RESULTS

4. RESULTS

The present investigation entitled "Evaluation of CMS based rice hybrids developed from rice varieties of Kerala identified as restorers" was undertaken to obtain information on synchronized flowering dates for CMS lines with restorers, analysis of variance, genetic parameters that included, standard heterosis, heterobeltiosis and grain quality parameter of the hybrids. The study comprised of cross involving CMS lines and identified restorers. The experiments were conducted at two locations *viz*., College of Agriculture, Vellayani, Thiruvananthapuram and Integrated Farming System Research Station (IFSRS), Karamana during *Virippu and Mundakan*, 2017-18. The data generated were subjected to statistical analysis. The results obtained are presented separately for both the experiments under the following heads:

4.1 Hybrid seed production

4.2 Evaluation of hybrids

4.1 HYBRID SEED PRODUCTION

4.1.1 Synchronization of Flowering in CMS and Restorers

The dates obtained for synchronized flowering is given in Table 5.

Variety 'Neeraja' got synchronization with CRMS31A when sown 10 days before while the restorers Remya and Jayathi got synchronization when sown along with CMS line. Swarnaprabha and Kanakom got synchronized flowering with CRMS31A when sown together. CRMS32A got synchronized flowering with the restorers Aiswarya, Mattariveni and Kanakom when sown together. Annapoorna had synchronized flowering with CRMS32A when sown 10 days after the sowing date of the CMS line.

4.1.2 Hybridization Attempted and Seeds Obtained

The cross between CRMS31A and Jayathi obtained the maximum (1957 Nos.) number of seeds where as CRMS31A x Swarnaprabha obtained the

Table 5. 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		√	

Table 6. Details of hybridization attempted and seed obtained

Female parent (CMS lines)	Male parents (Restorers)	Number of plants crossed	Average number of panicles crossed	Average No.seeds obtained panicle $^{-1}$	Number of seeds obtained in total
CRMS31A	Remya	22	6.54	13	1724
	Jayathy	18	5.32	17	1957
	Swarnaprabha	25	4.27	7	754
	Kanakom	21	5.87	14	1621
	Neeraja	20	5.94	12	1437
CRMS32A	Annapoorna	4	6.26	95	2357
	Aiswarya	30	7.65	3	126
	Mattatriveni	20	6.24	17	2347
	Kanakom	23	5.28	12	1839

Table 7. ANOVA table for 20 different characters

Sl.No.	Characters	Genotypes	Replication	Error	F Value
1	Plant height (cm)	185.16**	14.24	37.25	4.98
2	Number of productive tillers plant^{-1}	3.31*	10.94	0.71	4.68
3	Days to flowering	295.05**	46.33	0.67	442.57
4	Panicle length (cm)	20.57**	28.05	1.77	11.62
5	Pollen fertility	944.89**	198.22	12.63	74.83
6	Number of spikelets panicle^{-1}	6305.76**	1266.14	46.31	136.17
7	Days to maturity	313.54**	63.43	5.37	58.35
8	Number of filled grains panicle^{-1}	10204.22**	1930.97	170.85	59.72
9	Length-Breadth Ratio of grain	0.818**	0.129	0.09	9.47
10	1000 grain weight	6.48**	3.475	0.40	16.12
11	Grain yield (g) plant^{-1}	582.19**	99.17	5.42	107.33
12	Yield plot-1	9.055**	2.15	0.13	67.75
13	Optimum cooking time	16.05**	1.33	1.17	13.75
14	Volume expansion	0.28**	0.08	0.08	42.76
15	Kernel length (mm)	1.29**	0.09	0.08	14.78
16	Kernel breadth (mm)	0.10**	0.02	0.08	5.69
17	Kernel length by breadth ratio	0.82**	0.13	0.09	9.47
18	Head rice recovery in milling	143.38**	0.58	5.58	25.68
19	Amylose content	11.54**	0.01	1.79	6.40
20	Gelatinization Temperature	2.44**	0.01	0.28	8.80

*Significant at 0.05 level

**Significant at 0.01 level

minimum (754 Nos.) number of seeds. The cross between CRMS32A and Annapoorna obtained the maximum (2357 Nos.) number of hybrid seeds while the cross CRMS32A x Aiswarya obtained the minimum (126 Nos.) number of hybrid seeds.

4.2.1 Analysis of Variance for the Experimental Design

Significant differences were showed for all the characters at 0.01 level except number of productive tillers which was significant at 0.05 level (Table 7).

4.2.2 Mean Performance of Treatments

Mean performance of hybrids and checks is given in the Table 10 and 11. The classification of hybrids as per SES is given in Table 12. The yield and yield components of hybrids are compared with 'C1' in Figure.1

4.2.2.1 Observations on Morphological Characters

4.2.2.1.1 Plant Height (cm)

Plant height (cm) of all the hybrids were significantly higher than that of check variety C1 (94.48) except H4. The highest value for plant height was registered by the hybrid H5 (109.73) and the lowest by H4 (85). Others showed a mean performance *viz.*, H3 (98.04), H6 (99.06), H2 (104.8) and H1 (101.1). Only the hybrid H4 was shorter than the check variety C1.

4.2.2.1.2 Number of Productive Tillers Plant^{-1}

All the hybrids showed significantly higher values for number of productive tillers plant^{-1} than the check variety. The highest number of productive tillers was shown by H4 (11.86) and lowest by H1 (9.90) which was followed by H2 (9.93), H5 (10.33), H3 (10.47) and H6 (11.62). C1 showed a value of 8.84.

Table 8. Mean performance of hybrids and check varieties for yield and yield parameters.

Treatments	PH	TN	DF	PL	PF	SPP	DM	FGPP	GLBR	TGW	GYPP	YPP
C1	94.48	8.84	87.00	22.67	82.67	164.33	119.00	141.67	2.69	22.83	27.97	3.41
C2	86.52	8.73	77	20.5	72.94	77.83	109	71	2.92	27.27	16.5	2.24
H1	101.1	9.90	87.33	24.33	77.31	163.67	122.67	138.00	5.47	19.27	30.08	3.67
H2	104.82	9.93	86.67	24.33	75.36	293.33	118.67	179.00	5.17	22.83	25.40	3.00
H3	98.04	10.47	79.00	26.00	85.67	220.00	113.67	168.50	3.08	23.27	32.54	3.97
H4	85.00	11.86	63.00	29.33	47.33	219.00	94.67	43.67	5.63	20.63	6.61	0.76
H5	109.73	10.33	82.67	27.17	79.12	240.00	118.00	184.00	5.72	21.50	32.97	4.02
H6	99.06	11.62	67.67	29.53	48.35	183.5	103.00	54.30	5.23	20.40	8.54	1.04
Mean	97.34	10.21	78.79	25.48	71.09	195.21	112.34	122.52	4.71	22.25	22.58	2.76
SE (m)	2.13	0.78	0.63	0.97	1.24	18.29	2.04	1.03	0.38	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	0.82	1.76	9.09	0.56

PH- Plant height (cm), TN- Number of productive tillers plant^{-1}, DF- Days to flowering, PL- Panicle length (cm), PF- Pollen fertility (%), SPP- Number of spikelets panicle^{-1}, DM- Days to Maturity, FGPP- Number of filled grains panicle^{-1}, GLBR- Grain length by breadth ratio, TGW- Thousand grain weight (g), Grain yield plant^{-1} (g), YPP-Yield plot^{-1} (kg).

4.2.21.3 Days to Flowering (days)

The early flowering hybrids were H4 (63 days) and H6 (67.67 days) where as the check variety for earliness; 'Kanchana' took 77 days to flower. These were followed by H3 (79 days), H5 (82.67 days) and H2 (86.67 days). H1 took more days to flower *i.e.*87.33 days.

4.2.2.1.4 Panicle Length (cm)

The highest value for panicle length (cm) was registered by H6 (29.53 cm) which was followed by the other hybrids H4 (29.33 cm), H5 (27.17 cm), H3 (26 cm). H1 and H2 showed same value for panicle length (cm) *i.e.,* 24.33 cm. The hybrids H4 and H5 were on par with H6.The check variety C1 registered a panicle length of 22.67 cm. Panicles of hybrids with that of check and parents are shown in Plate. 4.

4.2.2.1.5 Pollen Fertility (%)

Among the hybrids, H3 showed maximum pollen fertility (85.67%) followed by H5 (79.12%). Pollen fertility of H3 was superior to the standard check (85.67%). Hybrid H3 also showed higher pollen fertility than the check variety. The other hybrids H6 and H4 had pollen fertility per cent around fifty *i.e.*, 48.35 % and 47.33% respectively. Pollen fertility of H1 (77.31 %) and H2 (75.36 %) were on par.

4.2.2.1.6 Number of Spikelets Panicle^{-1}

The highest value was recorded by the hybrid H2 (293.33) and the lowest by H1 (163.66). Others showed mean performance in the order, H5 (240), H3 (220), H4 (219) and H6 (183.5). Number of spikelets panicle^{-1} for the variety C1 was registered as 164.33 which was found to be on par with the hybrid H1.

4.2.2.1.7 Days to Maturity

H4 showed the lowest number of days to maturity (94.67 days) which was followed by H6 (103 days), H3 (113.67 days), H5 (118 days) and H2 (118.67 days). The highest value was registered by H1 (122.67 days). Only the hybrids H4 and H6 registered lesser days to maturity than the check variety 'Kanchana' for earliness.

4.2.2.1.8 Number of Filled Grains Panicle^{-1}

The highest number of filled grains panicle^{-1} was recorded by H5 (184) which was followed by H2 (179), H3 (168.5) and H1 (138). The lowest values were recorded by H4 (43.67) and H6 (54.3). Hybrids H2, H3 and H5 showed higher number of filled grains panicle^{-1} than the standard check C1 (141.67).

4.2.2.1.9 Length Breadth Ratio of Grain

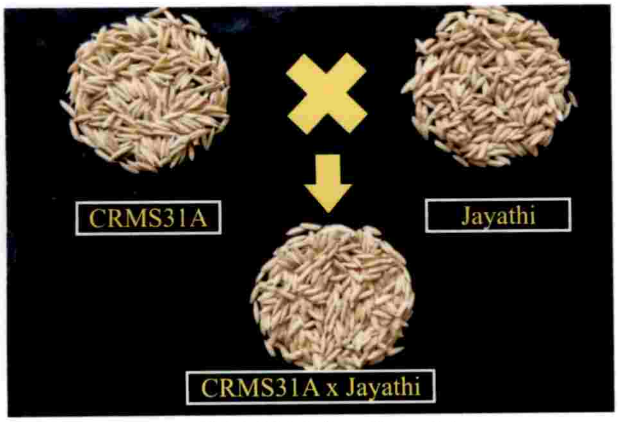
The highest length breadth ratio of grain among hybrids was observed for H5 (5.72) and lowest for H3 (3.08). The other hybrids showed a mean performance *viz.*, H4 (5.63), H1 (5.47), H6 (5.23) and H2 (5.17). 'C1' reported a ratio of 2.69 which was the lowest among the treatments. Grains of hybrids with that of check and parents are shown in Plate.3.

4.2.2.1.10 1000 Grain Weight (g)

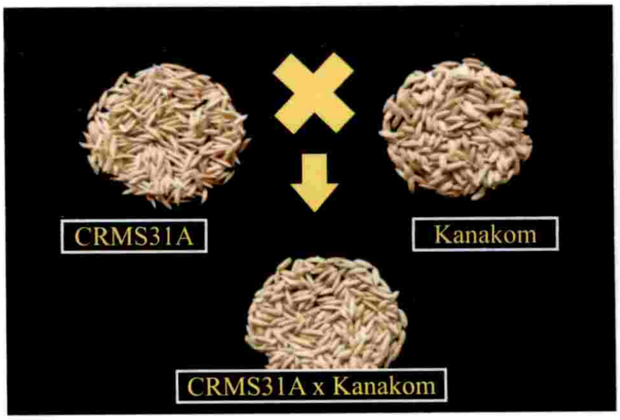
Thousand grain weight recorded maximum for the hybrid H3 (23.27g) and lowest for H1 (19.27g). Other hybrids showed an increasing order *viz.*, H6 (20.4g), H4 (20.63g), H5 (21.5g) and H2 (22.83g). H2 and H3 were on par with the standard check variety C1 (22.83g).

Plate 3: Grains of hybrids with that of parents and check

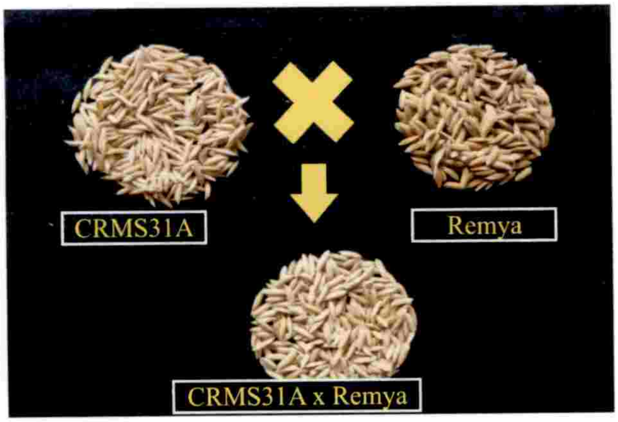
a. Uma



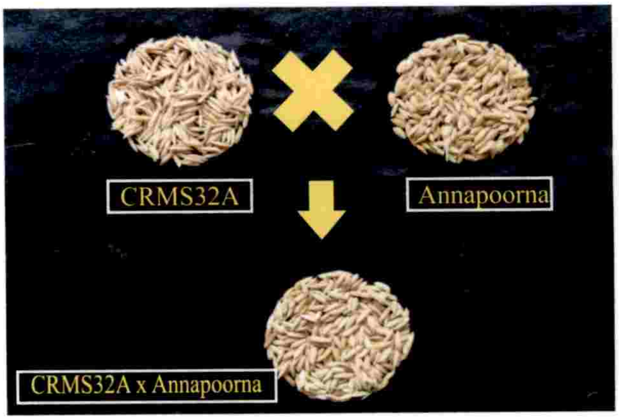
b. CRMS31A x Jayathi



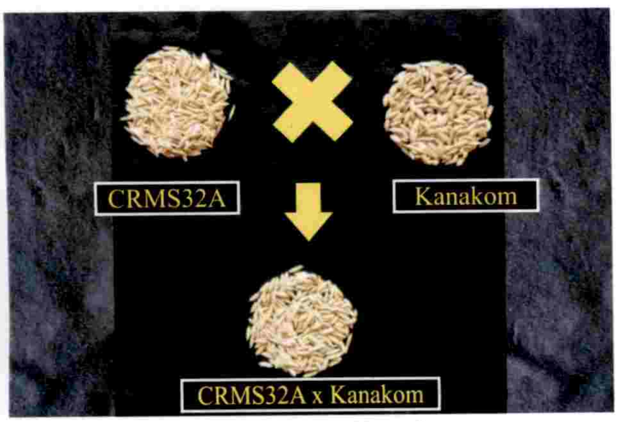
c. CRMS31A x Kanakom



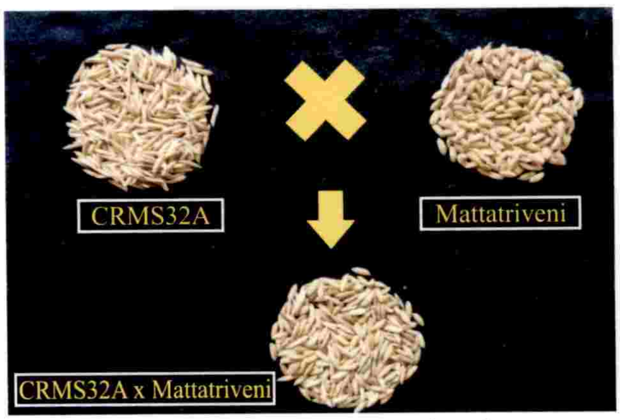
d. CRMS31A x Remya



e. CRMS32A x Annapoorna

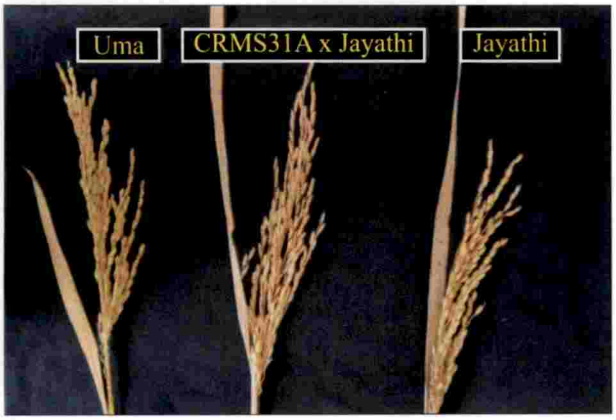


f. CRMS32A x Kanakom

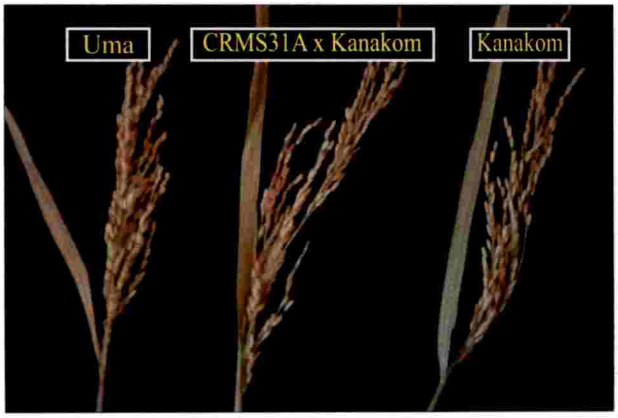


g. CRMS32A x Mattatriveni.

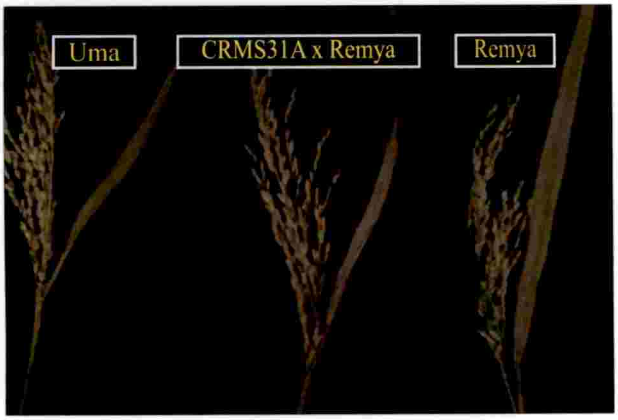
Plate 4. Panicles of hybrids along with that of check and restorers



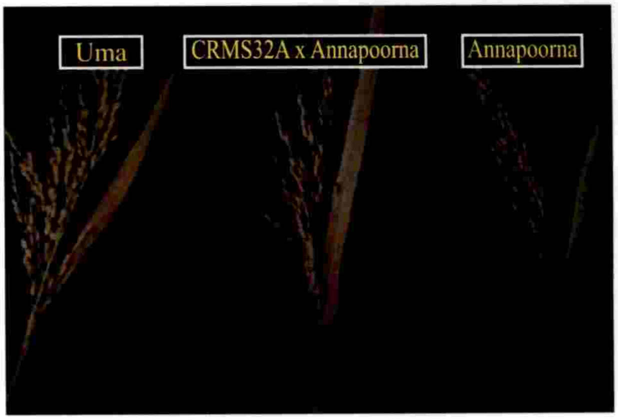
a. CRMS31A x Jayathi



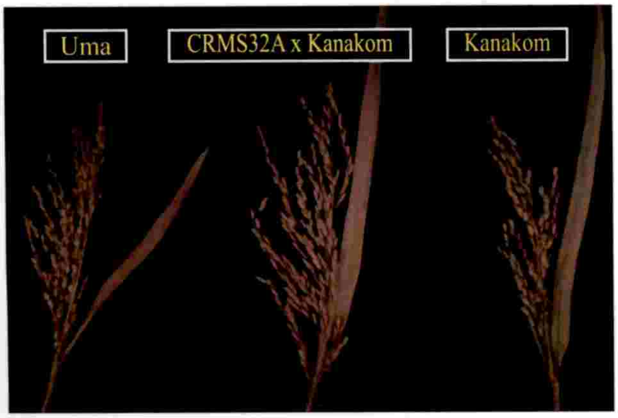
b. CRMS31A x Kanakom



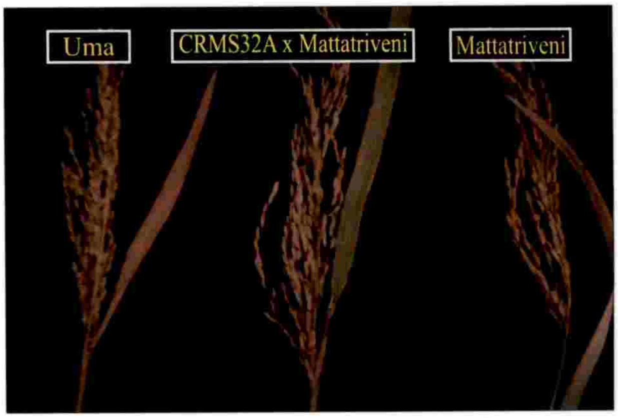
c.CRMS31A x Remya



d. CRMS32A x Annapoorna



e. CRMS32A x Kanakom



f. CRMS32A x Mattatriveni

4.2.2.1.11 Grain Yield (g) Plant^{-1}

Highest grain yield (g) plant^{-1} was recorded for H5 (32.97g) followed by H2 (25.4g), H3 (32.54g), H1 (30.08g), H6 (8.54g) and H4 (6.61g). C1 registered a value of 27.97g as grain yield plant^{-1}.

4.2.21.12 Yield Plot^{-1}(kg)

H5 recorded the highest value for yield plot^{-1}(4.022kg) followed by H3 (3.97kg) and H1 (3.67kg) which were found to be mutually on par. C1, the check variety reported a yield of 3.41 kg. These were followed by H2 (3.00kg), H6 (1.04kg) and H4 (0.76kg).

4.2.2.2 Cooking Quality

In Plate. 6 cooked rice of check, male parents and hybrids is shown.

4.2.2.2.1 Optimum Cooking Time

The range of values was from 22 to 25.67 minutes for hybrids. H1, H4 and H6 recorded same value *i.e.,* 25.667. The least value was recorded by H3 (22 minutes) followed by H2 (24) and H5 (25). C1, the check variety took more time to get cooked *i.e.,* 29.67 minutes (Plate. 6).

4.2.2.2.2 Volume Expansion

Volume expansion was maximum for H3 (3.63) followed by H2 (3.48), H6 (3.305), H1 (3.019), H5 (2.935) and H4 (2.922).Volume expansion of C1 was slightly smaller than the hybrids (2.85).

Table 9. Mean of hybrids and checks for grain quality parameters.

Treatments	OCT	VEX	KL	KB	KLBR	KC	HRRM	AC	GT
C1	29.67	2.85	5.16	2.48	2.08	Red	55	25.14	4.33
C2	31	3.22	6.3	2.15	2.94	Red	59.2	24.18	3.33
H1	25.67	3.02	6.09	2.49	2.46	White	60.00	26.08	3.33
H2	24.00	3.48	7.02	2.18	3.24	Red	49.00	25.76	5.00
H3	22.00	3.63	6.90	2.04	3.52	Red	43.00	24.48	5.67
H4	25.67	2.92	6.13	2.24	2.75	Red	45.00	27.28	5.33
H5	25.00	2.94	6.90	2.05	3.41	Red	57.30	22.55	6.00
H6	25.67	3.30	6.39	2.21	2.89	Red	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.

4.2.2.3 Grain Quality

The kernel dimensions of hybrid are compared with 'C1' in Figure. 2 and whole grain, milled and hulled grain of hybrids are given along with the check variety C1 in Plate. 5.

4.2.2.3.1 Kernel Length (mm)

The character kernel length had a range from 6.09 mm to 7.02 mm which were recorded by H1 (medium) and H2 (medium) respectively. Other hybrids showed values like H4 (6.13mm, Medium) and H6 (6.39mm, medium). Both H3 and H5 showed the same value for kernel length *i.e.*, 6.9 mm, which fell into 'long' category. Kernel length of C1 was found to be smaller than the hybrids (5.16 mm, medium).

4.2.2.3.2 Kernel Breadth (mm)

The lowest kernel breadth was reported by the hybrid H3 (2.04 mm) followed by H5 (2.05 mm), H2 (2.18 mm), H6 (2.21 mm), H4 (2.24 mm) and H1 (2.49 mm). The kernel breadth of the hybrid H1 was found to be on par with that of the check variety C1 (2.48 mm).

4.2.2.3.3 Kernel Length by Breadth Ratio

The lowest value was recorded by C1 (2.08, medium). Among hybrids, H4 recorded the lowest value (2.75, Medium) and the highest by H3 (3.52, slender). Other hybrids H2 (3.24, slender) and H5 (3.41, slender) was found to be on par with H3. H1 performed on par with the variety C1 for kernel length by breadth ratio.

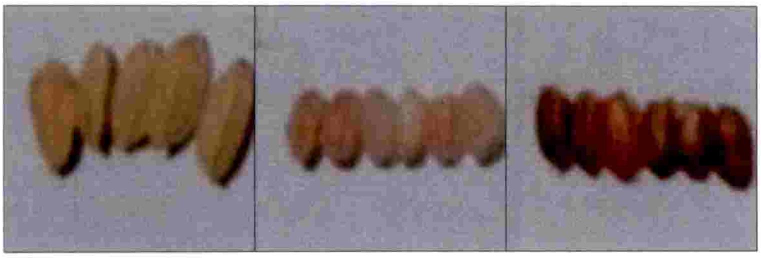
4.2.2.3.4 Kernel Colour

All the hybrids were red kernelled like the standard check 'C1' except H1, which was white kernelled.

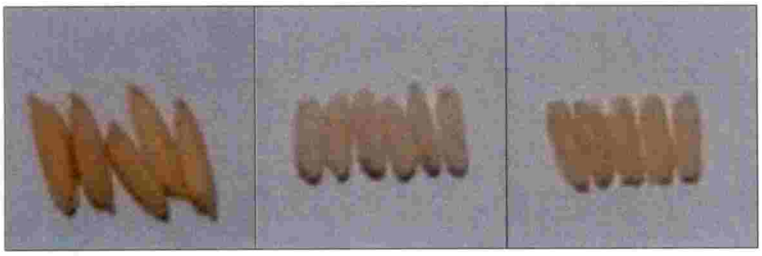
Table 10. Classification of hybrids and check as per Standard Evaluation System, IRRI (2002).

Hybrids	Kernel length	Kernel length by breadth ratio	Amylose content	Gelatinization temperature
C1	Medium	Medium	Intermediate	Intermediate(70^{o}c-74^{o}c)
H1	Medium	Medium	Intermediate	High, Intermediate
H2	Medium	Slender	Intermediate	Intermediate(70^{o}c-74^{o}c)
H3	Long	Slender	Intermediate	Intermediate(70^{0}c-74^{o}c)
H4	Medium	Medium	Intermediate	Intermediate(70^{0}c-74^{o}c)
H5	Long	Slender	Intermediate	Low(55^{o}c-69^{o}c)
H6	Medium	Medium	Intermediate	Intermediate(70^{0}c-74^{o}c)

Plate 5. Whole grain, milled and hulled grain of check and hybrids



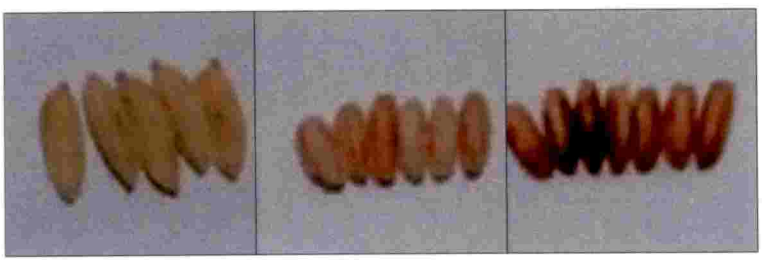
a. Uma



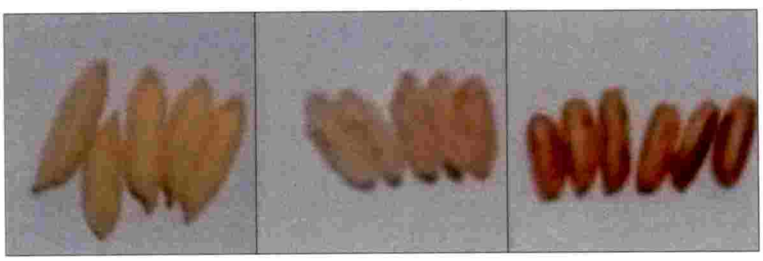
b. CRMS31A x Jayathi

c. CRMS31A x Kanakom

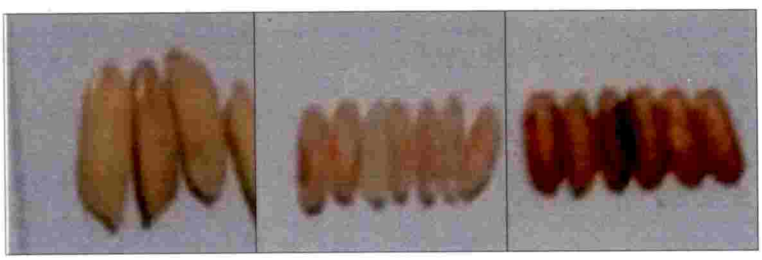
d. CRMS31A x Remya



e. CRMS32A x Annapoorna



f. CRMS32A x Kanakom



g. CRMS32A x Mattatriveni

Plate 6. Cooked rice of check, male parent and hybrids

a. Uma

b. Jayathi CRMS31A X Jayathi

c. Kanakom CRMS31A X Kanakom

d. Remya CRMS31A X Remya

e. Annapoorna CRMS32A X Annapoorna

f. Kanakom CRMS32A X Kanakom

g. Mattatriveni CRMS32A X Mattatriveni

4.2.2.4 Head Rice Recovery in Milling (%)

The head rice recovery in milling recorded a range from 43% (H3) to 60% (H1). The hybrids H2, H4, H5 and H6 recorded 49%, 45%, 57.3% and 59% respectively. Hybrids H5 and H6 were on par with that of check variety C1 (55%) for head rice recovery in milling.

4.2.2.5 Chemical Characterization

4.2.2.5.1 Amylose Content (%)

All the hybrids except H5 and H6 were of intermediate category for amylose content. The lowest value was recorded by H6 (21.78%) followed by H5 (22.55%), H3 (24.48%), H2 (25.76%), H1 (26.08%), and H4 (27.28%). C1 recorded a value of 25.14 per cent. H1, H2 and H3 were on par with the check variety C1 which also fell into intermediate category.

4.2.2.5.2 Gelatinization Temperature

The *per se* performance of hybrids showed the gelatinization temperature as: H1 (high/ intermediate), H2, H4, H3 and H6 (intermediate: 70-74^{0}C) and H5 (low: 55- 69°C). C1 showed an intermediate gelatinization temperature (70-74^{0}C).

4.2.3 Genetic Variability, Heritability and Genetic Advance

Different genetic parameters are given in the Table 11 and 12 for yield and yield component traits and for grain quality parameters respectively. The values are represented in the Figure.3 and Figure.4.

4.2.3.1 Observations on Morphological Characters

4.2.3.1.1 Plant Height (cm)

The genotypic and phenotypic coefficient of variation estimates observed for this trait was low *i.e.,* 7.44 and 9.98 respectively. The observed heritability estimates for this character was medium (55.53) with moderate genetic advance as per cent of mean (11.42).

4.2.3.1.2 Number of Productive Tillers Plant^{-1}

The genotypic coefficient of variation for number of productive tillers plant^{-1} was low (6.04) while phenotypic coefficient of variation was moderate (10.75). The observed heritability estimate was medium (31.52) with a low genetic advance as per cent of mean (6.98).

4.2.3.1.3 Days to Flowering

The genotypic and phenotypic coefficients of variation were moderate for this trait *i.e.,* 13.06 and 13.09 respectively. The observed heritability estimate for this character was high (99.46) with a high genetic advance as per cent of mean (26.83).

4.2.3.1.4 Panicle Length (cm)

The genotypic coefficient of variation as well as phenotypic coefficient of variation was low for this character *i.e.,* 8.22 and 9.36 respectively. This character recorded higher heritability estimate (77.23) with a moderate genetic advance as per cent of mean (14.89).

4.2.3.1.5 Pollen Fertility (%)

High genotypic and phenotypic coefficient of variation was observed for pollen fertility per cent with high heritability (96.07) and high genetic advance as per cent of mean (56.48).

Table 11. Genetic parameters for yield and yield components

Character	GCV(%)	PCV(%)	H^2 (%)(BroadSense)	GA as per cent of mean (5%)
Plant Height	7.44	9.98	55.53	11.417
Number of productive tillers $plant^{-1}$	6.037	10.75	31.52	6.98
Days to flowering	13.062	13.099	99.43	26.83
Panicle length (cm)	8.22	9.361	77.23	14.89
Pollen fertility (%)	27.15	27.71	96.067	56.48
Number of spikelets $panicle^{-1}$	20.25	22.49	81.08	36.18
Days to maturity	9.533	9.79	94.77	19.11
Number of filled grains $panicle^{-1}$	49.132	50.22	95.67	95.99
Length-breadth ratio of grain	19.361	20.51	89.057	35.02
Thousand grain weight	6.941	7.577	83.915	11.19
Grain yield (g) $plant^{-1}$	52.719	53.389	97.504	92.107
Yield $plot^{-1}$	52.625	53.783	95.741	106.074

4.2.3.1.6 Number of Spikelets Panicle^{-1}

High genotypic (20.25) and phenotypic coefficient of variation (22.49) was observed for this trait. A high heritability (81.08) and genetic advance as per cent of mean (36.18) were also noted for the character.

4.2.3.1.7 Days to Maturity

A low genotypic and phenotypic coefficient of variation was observed for the character *i.e.*, 9.53 and 9.79 respectively. Heritability was high but genetic advance as per cent of mean recorded low value (19.11).

4.2.3.1.8 Number of Filled Grains Panicle^{-1}

A high genotypic (49.13) and phenotypic (50.22) coefficient of variation was observed for this character. The heritability estimate was high (95.67) with a high genetic advance as per cent of mean (95.99).

4.2.3.1.9 Length - Breadth Ratio of Grain

For length breadth ratio of grain, the genotypic coefficient of variation was moderate (19.36) while phenotypic coefficient of variation was high (20.51) with a high value of heritability (89.06) and genetic advance as per cent of mean (35.02).

4.2.3.1.10 1000 Grain Weight

A low genotypic coefficient of variation (6.94) and phenotypic coefficient of variation (7.57) were recorded for this trait. The heritability estimate was high (83.9) and genetic advance as per cent of mean was moderate (11.19).

4.2.3.1.11 Grain Yield (g) Plant^{-1}

All the genetic parameters recorded high value for this trait *i.e.,* genotypic coefficient of variation (52.72), phenotypic coefficient of variation (53.39), heritability (97.5) and genetic advance as per cent of mean (92.2).

4.2.3.1.12 Yield Plot^{-1}(kg)

All the genetic parameters recorded high value for this trait *i.e.* genotypic coefficient of variation (52.63), phenotypic coefficient of variation (53.78), heritability (95.74) and genetic advance as per cent of mean (106.07).

4.2.3.2 Cooking Quality

4.2.3.2.1 Optimum Cooking Time (minutes)

Low genotypic coefficient of variation (5.46) and phenotypic coefficient of variation (6.76) was reported for this character. The heritability reported a higher value but the genetic advance as per cent of mean was low (9.08).

4.2.3.2.2 Volume Expansion

The low genotypic coefficient of variation (9.62) and phenotypic coefficient of variation (9.59) was reported by this character. The heritability estimate was high (93.01) while the genetic advance as per cent of mean was medium (18.38).

4.2.3.3 Grain Quality

4.2.3.3.1 Kernel Length (mm)

The GCV and PCV were low for these traits *i.e.,* 5.8 and 7.47 respectively. Heritability estimate was high (60.24) but genetic advance as per cent of mean was low value (9.27).

Table 12. Genetic parameters for grain quality traits.

Character	GCV (%)	PCV (%)	H^2 (%) (Broad Sense)	GA as per cent of mean (5%)
Optimum cooking time (min)	5.46	6.76	65.20	9.08
Volume expansion	9.26	9.59	93.01	18.38
Kernel length (mm)	5.80	7.47	60.24	9.27
Kernel breadth (mm)	6.71	9.14	53.93	10.15
Kernel length by breadth ratio	12.17	15.82	59.31	19.33
Head rice recovery in milling (%)	14.06	14.86	89.52	27.40
Amylose content (%)	8.15	9.64	71.55	14.20
Gelatinization temperature	17.79	20.09	78.35	32.43

4.2.3.3.2 Kernel Breadth (mm)

Low genotypic (6.71) and phenotypic coefficient of variation (9.14) was reported for this character. A high heritability estimate was recorded for kernel breadth (53.93) with a moderate genetic advance as per cent of mean (10.15).

4.2.3.3.3 Kernel Length by Breadth Ratio

Moderate genotypic coefficient of variation (12.17) and phenotypic coefficient of variation (15.82) was observed for kernel length by breadth ratio. The heritability was high for this character (59.31) with a genetic advance as per cent of mean of 19.33 which fell into the category 'moderate'.

4.2.3.4 Head Rice Recovery in Milling (%)

A moderate GCV (14.06) and PCV (14.86) were reported by this trait. A high heritability (89.52) along with high genetic advance as per cent of mean (27.4) was also recorded.

4.2.3.5 Chemical Characterization

4.2.3.5.1 Amylose Content (%)

A low genotypic (8.15) and phenotypic coefficient of variation (9.64) was observed for this trait. A high heritability estimate (71.55) along with moderate genetic advance as per cent of mean (14.2) was also recorded.

4.2.3.5.2 Gelatinization Temperature

The genotypic coefficient of variation was moderate (17.79) while the phenotypic coefficient of variation was high (20.09). A high heritability (78.35) along with high genetic advance as per cent of mean (32.43) was recorded.

4.2.4. Standard Heterosis

The results for standard heterosis are depicted in Table 15 and 16.

4.2.4.1 Observations on Morphological Characters

4.2.4.1.1 Plant height (cm)

H5 showed the highest value of positive heterosis (16.13) followed by H2 (10.93), H1 (6.98), H6 (4.84) and H3 (3.76). Negative heterosis was shown only by the hybrid H4 (-10.03). None of the crosses showed significant standard heterosis for this trait.

4.2.4.1.2 Number of Productive Tillers Plant^{-1}

Only H4 and H6 showed positive significant value of standard heterosis of 34.84 and 31.8 respectively. Also all the other hybrids showed positive heterosis *viz.*, H3 (18.94), H5 (17.42), H2 (12.87) and H1 (12.5).

4.2.4.1.3 Days to Flowering

Only two hybrids H4 and H6 showed negative heterosis of -18.53 and -12.49 over the earliest check variety Kanchana. All the other hybrids showed positive heterosis. The highest positive heterosis for this character was observed for the hybrid H1 (12.93) followed by the hybrids H2 (12.07), H5 (6.9) and H3 (2.15).

4.2.4.1.4 Panicle Length (cm)

The highest significant value for this trait was shown by H6 (30.15) followed by H4 (29.4). This was followed by other hybrids *viz.*, H5 (19.85), H3 (14.7). Both H1 and H2 showed same values for heterosis for panicle length (cm) *i.e.*, 7.35.

Table 13. Standard heterosis of the hybrids over the varieties Uma and Kanchana.

Hybrids	PH	TN	DF	PL	PF	SPP	DM	FGPP	GLBR	TGW	GYPP	YLD
H1	6.98	12.5	12.93*	7.35	-6.48	-0.41	12.53*	-2.588	103.09**	-15.62	7.54	7.58
H2	10.93	12.87	12.07	7.35	-8.83	78.49	8.87	26.588	92.07**	0.01	-9.18	-9.12
H3	3.76	18.94	2.16	14.7*	3.63	33.87	4.28	18.94	14.179	1.898	16.33	16.37
H4	-10	34.85*	-18.53**	29.4**	-42.74**	33.67	-13.15*	-69.18**	109.07**	-9.635	-77.6**	-76.37**
H5	16.13	17.42	6.9	19.85*	-4.29	46.15**	8.25	29.88	112.36**	-5.839	17.87	17.91
H6	4.84	31.8*	-12.49*	30.15**	-41.51**	11.66	-5.50	-61.67*	94.098**	-10.65	-69.92**	-69.45**

PH- Plant height (cm), TN- Number of tillers per plant, DF- Days to flowering, PL- Panicle length (cm), PF- Pollen fertility (%), SPP- Number of spikelets panicle^{-1}, DM- Days to Maturity, FGPP- Number of filled grains panicle^{-1}, GLBR- Grain length by breadth ratio, TGW- Thousand grain weight (g), Grain yield plant^{-1} (g), YPP-Yield plot^{-1} (kg).

*Significant at 0.05 level

**Significant at 0.01 level.

4.2.4.1.5 Pollen Fertility (%)

All the hybrids showed negative heterosis for this character except H3 (3.63). The highest significant negative heterosis was shown by H4 (-42.74) followed by H6 (-41.51). Other hybrids showed a standard heterosis *viz.*, H2 (-8.83), H1 (-6.48) and H5 (-4.29).

4.2.4.1.6 Number of Spikelets Panicle^{-1}

The hybrid H2 showed significant positive heterosis of 78.49 followed by H5 (46.15). Negative heterosis was shown by H1 (-0.41). H6 showed a positive heterosis of 11.66, H4 of 33.67 and H3 of 33.87.

4.2.4.1.7 Days to Maturity

As like days to flowering, H4 and H6 showed a negative heterosis of -13.15 and -5.5 respectively. All the other hybrids showed positive heterosis: H3 (4.28), H5 (8.256), H2 (8.87) and H1 (12.53).

4.2.4.1.8 Number of Filled Grains Panicle^{-1}

Three hybrids showed negative and other three showed positive heterosis for number of filled grains panicle^{-1}. The highest positive heterosis was shown by H5 (29.88) followed by H2 (26.58) and H3 (18.94). The lowest standard heterosis for the trait was shown by H4 (-69.18) followed by H6 (-61.67) and H1 (-2.59).

4.2.4.1.9 Length- Breadth Ratio of Grain

This is the character that showed highest standard heterosis compared with C1, since the grains of all the hybrids were longer than standard check. Highest significant standard heterosis was observed for H5 (112.36) and lowest for H3 (14.18). Other significant results were obtained for H4 (109.06), H1 (103.09), H6 (94.09) and H2 (92.07).

4.2.4.1.10 1000 grain weight

None of the hybrids recorded significant positive heterosis for this trait. Positive value (1.89) was recorded only by H3. The lowest value was recorded for H1 (-15.62) followed by H6 (-10.65), H4 (-9.63) and H5 (-5.83). The hybrid H2 showed a value of zero for standard heterosis for this trait.

4.2.4.1.11 Grain Yield (g) Plant^{-1}

The highest value of heterosis was shown by H5 (17.87) followed by H3 (16.33) and H1 (7.54). H4 showed the highest negative heterosis of -77.6 followed by H6 (-69.92. H2 recorded the negative heterosis of -9.18.

4.2.4.1.12 Yield Plot^{-1}(kg)

Except three hybrids, all others showed positive heterosis. The highest positive heterosis was observed by H5 (17.9) followed by H3 (16.37), H1 (7.58). The lowest significant values were recorded by H4 (-76.37) and H6 (-69.45). H2 registered a non significant negative heterosis of -9.12. Standard heterosis for yield plot^{-1} is compared in Figure. 5.

4.2.4.2 Cooking Quality

4.2.4.2.1 Optimum Cooking Time

All the hybrids recorded a significant negative heterosis for this character. The lowest value was observed for H3 (-25.84) followed by H2 (-19.10) and H5 (-15.73). The three hybrids (H1, H4 and H6) showed the same value of standard heterosis as -13.48.

4.2.4.2.2 Volume Expansion

Three of the hybrids showed significant positive heterosis *i.e.,* H3 (27.50), H2 (22.31) and H6 (16.08). These were followed by H1 (6.05), H5 (3.09) and H4 (2.65).

Table 14. 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*

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

4.2.4.3 Grain Quality

4.2.4.3.1 Kernel Length (mm)

All the hybrids except H1 (18.07) showed a significant positive heterosis for this character. The highest value was observed for H2 (36.19) followed by H5 (34.02), H3 (33.80), H6 (23.9) and H4 (18.89).

4.2.4.3.2 Kernel Breadth (mm)

Like kernel length, exception was observed for the hybrid H1 which showed a slight positive heterosis of 0.89. All other hybrids showed a significant negative heterosis. The lowest value was recorded by H3 (-17.67), followed by H5 (-17.67), H2 (-12.16), H6 (-10.86) and H4 (-9.64).

4.2.4.3.3 Kernel Length by Breadth Ratio

All the hybrids showed a positive standard heterosis for this character. Three of them showed a significant value, H3 (69.07), H5 (63.44) and H2 (55.28). A non significant positive heterosis was shown by the hybrids H6 (39.09), H4 (32.2) and H1 (17.9).

4.2.4.4 Head Rice Recovery in Milling (%)

The trait showed both positive and negative values. The highest positive heterosis was shown by H1 (9.09) followed by H6 (7.27) and H5 (4.24). The lowest value was registered by the hybrid H3 (-21.81) followed by H4 (-18.18) and H2 (-10.90).

4.2.4.5 Chemical Characterization

4.2.4.5.1 Amylose Content (%)

The lowest value was recorded by the hybrid H6 (-13.36) which was followed by H5 (-10.31) and H3 (-2.62). A positive value was recorded for H4 (8.51), H1 (3.72) and H2 (2.47).

4.2.4.5.2 Gelatinization Temperature

Except H1 (-23.07), all the other hybrids showed a positive heterosis. A significant heterosis was recorded for the hybrid H5 (38.46) along with H3 and H6 (30.76). These were followed by H4 (23.07) and H2 (15.38).

4.2.4 Heterobeltiosis

The mean performance of male parent for yield and quality is given in Table.15 and 17. The results for heterobeltiosis are presented in Table 16 and 18.

4.2.5.1 Observations on Morphological Characters

4.2.5.1.1 Plant Height (cm)

The heterobeltiosis for plant height (cm) was negative for all the hybrids except for H4 which showed positive heterobeltiosis of 6.13 per cent. The lowest heterobeltiosis for the character was recorded by H3 (-7.06) followed by H2 (-5.92), H5 (-1.52), H1 (-0.83) and H6 (-0 51). Five out of six hybrids were shorter than the better parents.

4.2.5.1.2 Number of Productive Tillers Plant^{-1}

All the hybrids showed positive heterobeltiosis for this character. Positive significant heterobeltiosis was observed for H4 (60.36) and H6 (34.88). Other hybrids

Table 15. Mean performance of male parents for yield and yield components.

Variety	PH	TN	DF	PL	PF	SPP	DM	FGPP	GLBR	TGW	GYPP	YPP
Annapoorna	81.00	7.4	68	19.33	66.47	97.67	97	93.33	4.68	23.03	14.06	1.71
Jayathi	103.14	9.067	92	30.33	92.67	135.5	123	136	5.49	19.77	19.78	2.41
Kanakom	112.74	8.533	92.67	22.17	77.83	164.17	121	144.67	3.31	27.8	21.89	2.68
Mattatriveni	93.034	8.6	72	25.33	87.89	151	104	139.67	2.66	25.37	19.86	2.49
Remya	106.74	8.067	84.33	25.83	92.33	167	116.33	130	5.54	27.97	41.26	5.04
Mean	99.33	8.33	81.8	24.59	83.44	143.07	112.27	128.73	4.34	24.79	23.37	2.87
SE (M)	2.358	0.761	0.58	0.933	4.103	7.13	1.049	1.02	0.191	0.326	2.525	0.072
C.D.	7.345	2.16	1.813	2.907	12.78	22.212	3.268	2.92	0.596	1.015	7.867	0.225

PH- Plant height (cm), TN- Number of tillers per plant, DF- Days to flowering, PL- Panicle length (cm), PF- Pollen fertility (%), SPP- Number of spikelets panicle^{-1}, DM- Days to Maturity, FGPP- Number of filled grains panicle^{-1}, GLBR- Grain length by breadth ratio, TGW- Thousand grain weight (g), Grain yield plant^{-1} (g), YPP-Yield plot^{-1} (kg).

Table 16. Heterobeltiosis for yield and yield components

Hybrid	PH	TN	DF	PL	PF	SPP	DM	FGPP	GLBR	TGW	GYPP	YLD
H1	-0.83	19.76	-5.07**	-19.78**	-16.56**	20.79**	-0.271	1.47	-0.37	-2.53	51.61**	52.02*
H2	-5.92	16.41	-6.47**	9.77	-3.17	78.68	-2.46	23.96	56.34**	-17.86**	16.03	15.92
H3	-7.06	29.75	-6.32**	0.65	-7.21	31.74	-2.29	29.61	-44.45**	-16.8**	-21.00	-21.15
H4	6.13	60.36**	-7.8**	51.72**	-28.78**	124.9**	-2.4	-53.21	20.25	-10.42	-53.00*	-52.71*
H5	-1.52	21.09	-10.79**	22.56*	1.67	46.29*	-3.01**	27.19	72.85**	-22.66**	49.54*	50.41*
H6	-0.51	34.88*	-6.45**	16.45**	-44.98**	21.52	-0.96**	-61.1**	12.71**	-19.58	-57.41**	-58.09**

PH- Plant height (cm), TN- Number of tillers per plant, DF- Days to flowering, PL- Panicle length (cm), PF- Pollen fertility (%), SPP- Number of spikelets panicle^{-1}, DM- Days to Maturity, FGPP- Number of filled grains panicle^{-1}, GLBR- Grain length by breadth ratio, TGW- Thousand grain weight (g), Grain yield plant^{-1} (g), YPP-Yield plot^{-1} (kg).

*Significant at 0.05 level

**Significant at 0.01 level.

that recorded positive heterobeltiosis were H3 (29.75), H5 (21.09), H1 (19.75) and H2 (16.4).

4.2.5.1.3 Days to Flowering

All the hybrids registered significant negative heterobeltiosis than their better parents. The lowest value was recorded by H5 (-10.79) followed by H4 (-7.8), H2 (-6.47), H6 (-6.45), H3 (-6.32). The highest heterobeltiosis for days to flowering was registered by H1 (-5.07).

4.2.5.1.4 Panicle Length (cm)

H1 registered a significant negative heterobeltiosis (-19.78). All the other hybrids showed positive heterobeltiosis. The highest significant positive heterobeltiosis was observed for the hybrid H4 (51.72) and lowest by H3 (0.65). Other hybrids recorded a heterobeltiosis of positive values *viz.*, H5 (22.56), H6 (16.45) and H2 (9.77).

4.2.5.1.5 Pollen Fertility (%)

A significant negative heterobeltiosis was found for this character for hybrids H1 (-16.56), H4 (-28.78) and H6 (-44.98). All others showed a non significant negative heterobeltiosis *viz.*, H3 (-7.21), H2 (-3.17) and H5 (1.67).

4.2.5.6.1 Number of Spikelets Panicle^{-1}

All the hybrids showed a positive heterobeltiosis for this character. Significant values are observed for H4 (124.91), H2 (78.68) and H5 (46.29). Other hybrids also showed a non significant positive heterobeltiosis *viz.*, H3 (31.73), H6 (21.52) and H1 (20.78).

4.2.5.1.7 Days to Maturity

All the hybrids showed negative heterobeltiosis. The lowest value was recorded by H5 (-3.01) followed by H1 (-0.271), H2 (-2.46), H4 (-2.4), H3 (-2.29) and H6 (-0.96).

4.2.5.1.8 Number of Filled Grains Panicle^{-1}

The highest value of heterobeltiosis for number of filled grains panicle^{-1} was recorded by H3 (29.61) followed by H5 (27.19), H2 (23.96) and H1 (1.47). Lowest significant value for this trait was observed for H6 (-61.12) and H4 (-53.21).

4.2.5.1.9 Length- Breadth Ratio of Grain

A significant negative heterobeltiosis was recorded by the hybrid H3 (-44.45). A negative value was observed for H1 (-0.37). Significant positive heterobeltiosis was observed for H5 (72.85), H2 (56.34) and H6 (12.71). A positive value was shown by H4 (20.25).

4.2.5.1.10 1000 Grain Weight

All the hybrids showed negative heterobeltiosis for this character. The lowest value was recorded for H5 (-22.66), H2 (-17.86) and H3 (-16.8). A negative heterobeltiosis was observed for other hybrids like H6 (-19.58), H4 (-10.42) and H1 (-2.53).

4.2.5.1.11 Grain Yield (g) Plant^{-1}

The hybrids H6 and H4 showed a significant negative heterobeltiosis for this character of -57.41 and -53 respectively. All other hybrids showed positive heterobeltiosis. A significant value was recorded for the hybrids H1 (51.61) and H5 (49.54). H2 reported a value of 16.03 per cent heterobeltiosis over the better parent.

4.2.5.1.12 Yield Plot[1] (kg)

Three hybrids showed positive and three hybrids showed negative heterobeltiosis for this character. Positive values were recorded by H5 (52.41), H1 (52.02) and H2 (15.92). Negative values are reported by the hybrids H6 (-58.09), H4 (-52.71) and H3 (-21.15). Heterobeltiosis for hybrids is depicted in Figure.6.

4.2.5.2 Cooking Qualities

4.2.5.2.1 Optimum Cooking Time

A significant positive heterobeltiosis was recorded by H1 (40). H3 recorded heterobeltiosis for this character as 11.86 per cent. All other hybrids recorded a negative value. Lowest value was registered as -23 by H6 followed by H4 (-8.33), H2 (-6.49) and H5 (-2.59).

4.2.5.2.2 Volume Expansion

The highest significant heterobeltiosis for volume expansion was recorded for the hybrid H4 (22.58) followed by H3 (21.94), H2 (13.36), H1 (5.08). A significant negative heterobeltiosis was recorded by H4 (-4.45) and H6 (-3.68).

4.2.5.3 Grain Quality

4.2.5.3.1 Kernel Length (mm)

The highest heterobeltiosis was recorded for the hybrid H4 (41.99) and the lowest by H1 (1.48) which was followed by H3 (2.81), H5 (4.19), H2 (5.88) and H6 (23.94).

4.2.5.3.2 Kernel Breadth (mm)

All the hybrids except H1 (10.79) reported a negative heterobeltiosis for this trait *i.e.*, H2 (-4.02), H3 (-4.92), H5 (-9.61), H6 (-6.71) and H4 (-15.69).

Table 17. Mean performance of male parent for grain quality parameters

Variety	OCT	VEX	KL	KB	KLBR	KC	HRRM	AC	GT
Annapoorna	28	2.38	4.32	2.65	1.63	Red	57	21.82	2.33
Jayathi	18.33	2.87	6	2.26	2.69	White	53	19.67	2.67
Kanakom	25.67	3.07	6.63	2.27	2.93	Red	50	25.8	4.33
Mattatriveni	33.33	3.43	5.16	2.37	2.19	Red	66	28.3	2.67
Remya	19.67	2.98	6.71	2.14	3.16	Red	45	28.13	5.33
Mean	25	2.95	5.77	2.34	2.52		54.2	24.74	3.47
SE(M)	0.638	0.148	0.132	0.159	0.075		0.406	0.482	0.241
C.D.	1.989	0.46	0.412	0.159	0.232		1.264	1.501	0.752

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.

Table 18. Heterobeltiosis for grain quality parameters

Hybrids	OCT	VEX	KL	KB	KLBR	HRRM	AC	GT
H1	40**	5.02	1.48	10.79	-8.83	13.21*	32.59**	25.01
H2	-6.49	13.36**	5.88	-4.02	10.45	-2.00	-0.14	15.38
H3	11.86	21.94	2.81	-4.92**	11.41	-4.44	-12.98	6.25
H4	-8.33	22.58**	41.9**	-15.69*	68.96*	-21.05**	25.04**	128.57**
H5	-2.59	-4.45	4.19	-9.61	16.25	14.67*	-12.61	38.46*
H6	-23*	-3.68**	23.94*	-6.71	32.48	-10.61	-23.05	112.53*

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

4.2.5.3.3 Kernel Length by Breadth ratio

A positive significant heterobeltiosis was recorded by H4 (68.96) and the lowest by H1 (-8.83). The other hybrids recorded a positive heterobeltiosis *viz.*, H6 (32.48), H5 (16.25), H3 (11.41) and H2 (10.45).

4.2.5.3.4 Kernel Colour

All the hybrids except H1 were red kernelled. Hybrids had the kernel colour of better parent.

4.2.5.4 Head Rice Recovery in Milling (%)

Two of the hybrids showed a positive heterobeltiosis *i.e.,* H5 (14.66) and H1 (13.2). H4 showed negative significant heterobeltiosis (-21.05) and others showed a negative heterobeltiosis; H6 (-10.61), H3 (-4.44) and H2 (-2).

4.2.5.5 Chemical Characterization

4.2.5.5.1 Amylose Content (%)

The lowest value was registered by H6 (-23.04) followed by H3 (-12.9), H5 (-12.61) and H2 (-0.14). A positive significant heterobeltiosis was observed for H1 (35.59) and H4 (25.04).

4.2.5.5.2 Gelatinization Temperature

All the hybrids showed a positive value for this character. The lowest value was shown by H3 (6.25) followed by H2 (15.38), H1 (25.01) and H5 (38.46). The highest value for this trait was recorded by the hybrids H4 (128.5) and H6 (112.5).

DISCUSSION

5. DISCUSSION

Rice (*Oryza sativa* L.) is the important food grain crop and staple food of Kerala. It is considered as the worlds' most diverse cereal crop. The demand of rice continues to rise in Kerala because of increase in population and improvement in living standards. Keralites are strict in their preference to quality aspects of rice. It is one of the rare places where the people prefer red kernelled bold rice grain types.

In the absence of scope of horizontal growth, among the various research strategies utilized for breaking the yield barriers, the development of hybrid rice is of prime importance. Technology of hybrid rice will provide a chance to trigger the yield of rice and to break through the yield plateau of semi dwarf varieties. According to Virmani (1996), varieties of hybrid rice with yield preferred standpoint of 15-20 per cent over the traditional high yielding varieties can be released for commercial production. Since rice is an autogamous crop, in order to develop and produce F_1 rice hybrids, an effective male sterile system must be involved. The advancement and utilization of varieties of hybrid rice on a large scale exploiting cytoplasmic male sterility- fertility restoration framework has confirmed to be one of the points of reference in rice improvement history. 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 hybrid combination with more than 15% yield advantage over the commercially accepted varieties when developed through the three line system.

With the enhanced income levels and changing food habits, breeding rice varieties with preferred grain quality features like red kernel colour, boldness, amylose content etc has become an important objective along with yield in Kerala. Combining yield potential with good grain quality is hence one of the challenging areas of rice breeding. Important physical properties include yield of edible and marketable polished grain, uniform shape and redness which are immediately obvious to consumers and these characters determine market value. Good milling quality and cooking quality traits are also the important factors to be considered in breeding programmes. Predictable expression of all the yield contributing traits combined with quality parameters across seasons and years gives status to an accession as a hybrid variety.

So in view of the demand for hybrids with good yield and grain quality, this investigation was carried out to evaluate six hybrids developed from the probable restorers identified from rice varieties of Kerala. CRMS31A and CRMS32A (The male sterile lines developed by NRRI, Cuttack) were used as male sterile female parent.

The present investigation was conducted in two experiments

1. Hybrid seed production
2. Evaluation of hybrids.

The results of two experiments are discussed in subheads below.

5.1. HYBRID SEED PRODUCTION.

Hybrid seed production was carried out during May to August 2017 (*Virippu, 2017*). This experiment could identify the 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. For three hybrids, male parents which were sown 10 days after CMS got synchronized flowering. In one cross combination, Neeraja with CRMS31A, synchronized flowering was obtained for 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.

A hybrid with the capability of being discharged for business development ought to fundamentally outperform the yield level of the best locally adjusted variety and need to guarantee hybrid seed production in mass amounts. 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 cannot 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.

5.2. EVALUATION OF HYBRIDS

Six hybrids were evaluated along with check varieties Uma and Kanchana in IFSRS Karamana during October 2017 to February 2018 (*Mundakan, 2017-18)*.

5.2.1. Genetic Parameters

Investigation on the analysis of variance demonstrated that all the hybrids varied altogether for the characteristics considered. The limited difference between phenotypic and genotypic elements of variation for majority of the characters disclosed less influence of environment. This finding is in close agreement with the observations of Singh *et al.* (1985), Alam *et al.* (1989), Alam *et al.* (1998), Nuruzzaman *et al.* (2002) and Rahimi *et al.* (2010), in evaluating hybrids. Yield plot^{-1} showed the highest GCV and PCV followed by grain yield (g) plant^{-1}, length-breadth ratio of grain and number of spikelets panicle^{-1}.

A high broad sense heritability alongside high genetic advance (GA) as per cent of mean is normally more accommodating in anticipating the resultant impact for determination of the best genotypes than heritability alone (Jhonson *et al.*, 1995). In the present investigation, a high heritability for days to flowering, panicle length, pollen fertility, number of spikelets panicle^{-1}, number of filled grains panicle^{-1},

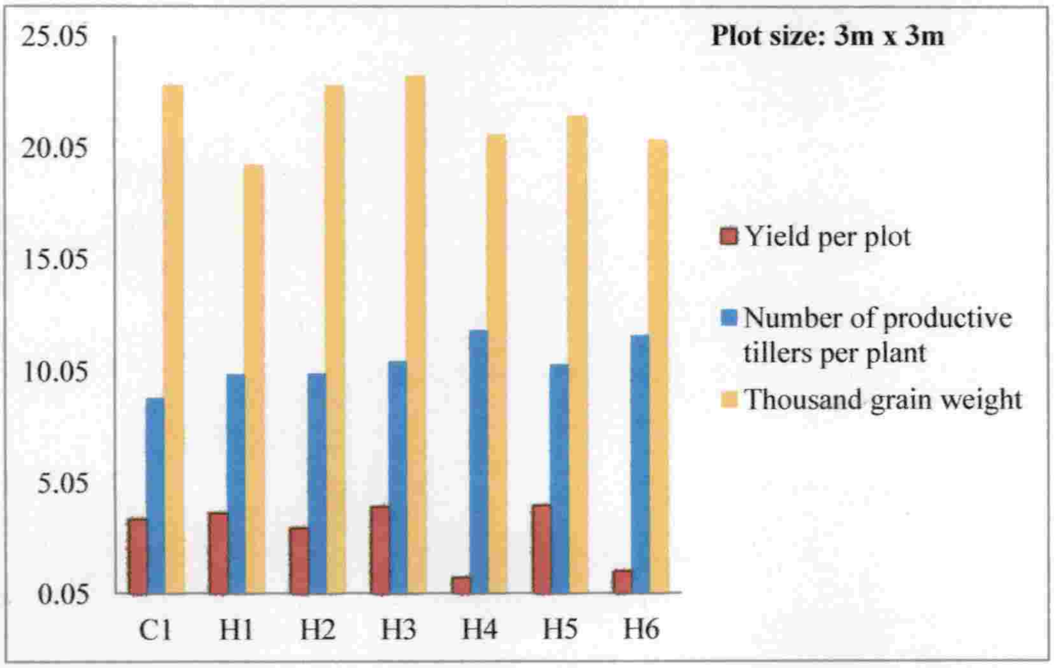


Fig. 1. Yield and yield components of hybrids compared with that of the variety 'Uma'

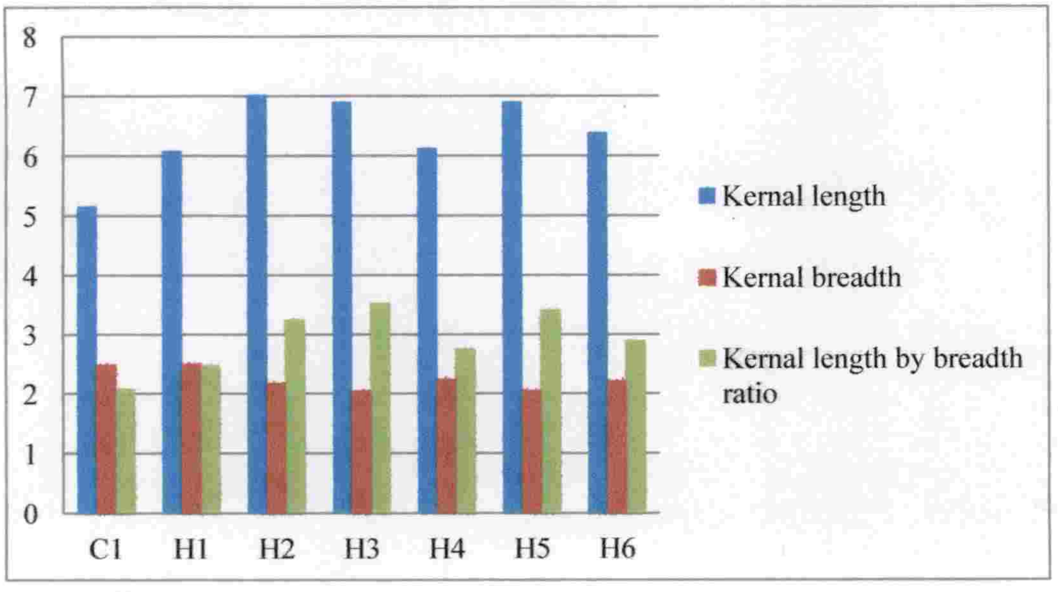


Fig. 2. Kernel dimensions of hybrids compared with that of the variety 'Uma'

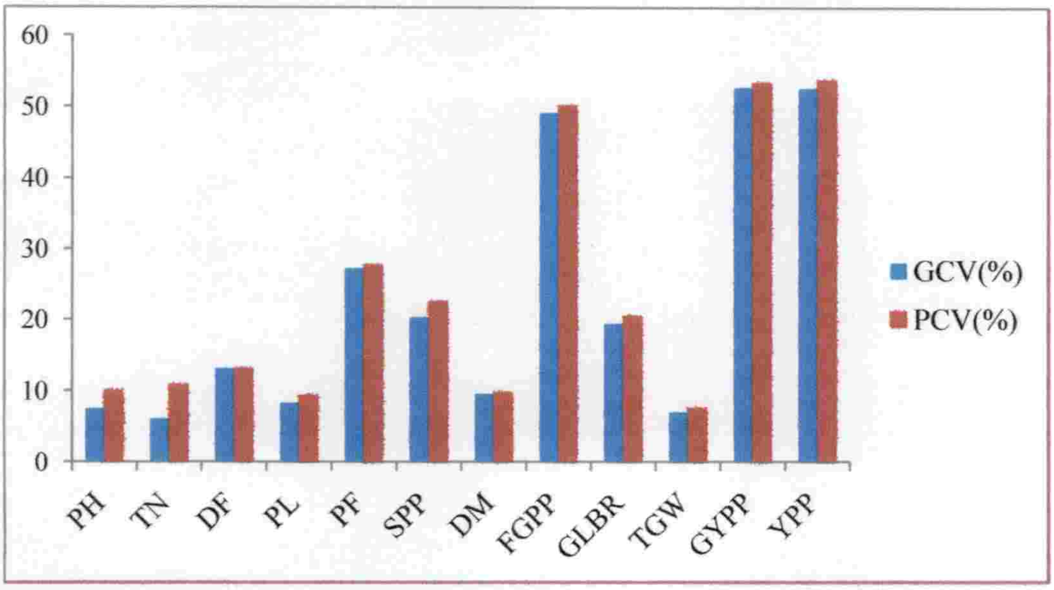


Fig. 3. Genetic parameters for yield and yield components

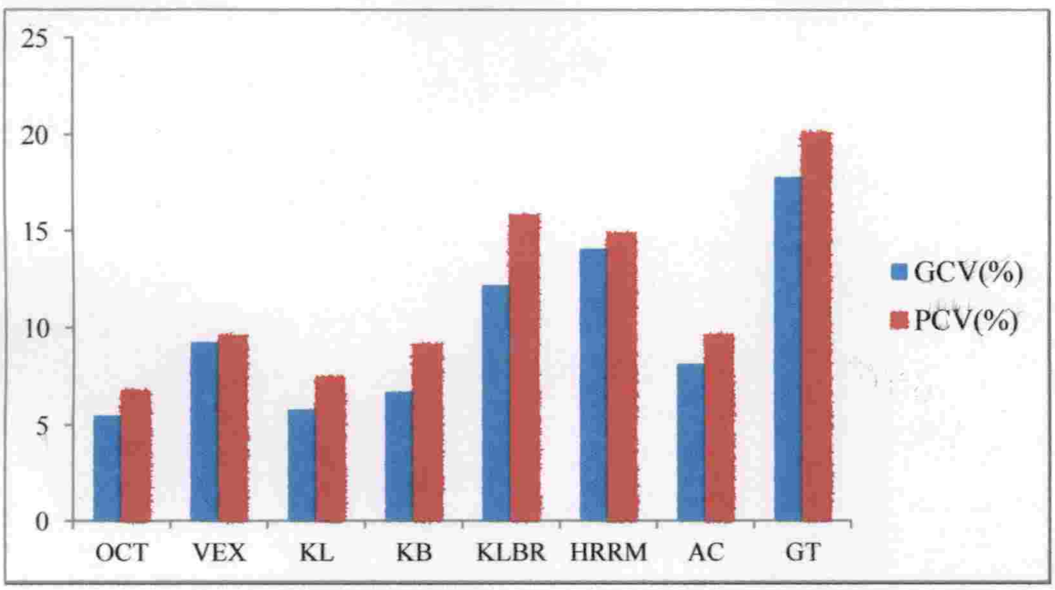


Fig. 4. Genetic parameters for grain quality traits

length-breadth ratio of grain, grain yield (g) plant^{-1} and yield plot^{-1} were related with high GA as per cent of mean, demonstrating the presence of additive gene effects in controlling these traits. In this manner impressive extent of change of rice exists by selection after these characters. Comparative discoveries were additionally revealed by Singh *et al.* (1985), Alam *et al.* (1989), Alam *et al.* (1998) and Rahimi *et al.* (2010).

5.2.2. Mean performance of hybrids and checks.

Among the six hybrids, H5 (CRMS32A x Kanakom), H3 (CRMS31A x Remya), H1 (CRMS31A x Jayathi) gave higher yield than the standard check Uma. The yield component traits such as number of productive tillers, 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 (CRMS32A x Kanakom) was superior to the standard check. This shows that the variety Kanakom is a complete restorer for male sterile cytoplasm CRMS32A. Hybrid H3 (CRMS31A x Remya) also showed pollen fertility on par with the check. Hence the variety Remya is a restorer for CRMS31A. The other hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) had pollen fertility per cent around 50. So the male parents Annapoorna and Mattatriveni for CRMS32A can be considered as partial restorers. The low level of pollen fertility was the reason for low yield of hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) despite high number of productive tillers. The hybrid H1 (CRMS31A x Jayathi) gave on par yield with Uma even though the pollen fertility was considerably low. Singh *et al.,* (2006) also reported a similar case. The varieties in conduct of restoration of fertility demonstrate that either the fertility reestablishing genes are unique or that their penetrance and expressivity changed with the genotypes of the parents or with the modifiers of female genetic background.

For days to maturity, the hybrids H1 (CRMS31A x Jayathi) and H2 (CRMS31A x Kanakom) were on par with that of Uma, where as the hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) matured earlier than the standard check Kanchana. The male parent of hybrid H4 (CRMS32A x Annapoorna) was Annapoorna which had a short duration of 95 days. From the evaluation of hybrids it is seen that the duration of male parent decided the duration of hybrids.

The thousand grain weight was lower than Uma for all the hybrids except H3 (CRMS31A x Remya). This trait of H2 (CRMS31A x Kanakom) was on par with that of Uma. But the 1000 grain weight for the hybrids H5 (CRMS32A x Kanakom), H4 (CRMS32A x Annapoorna), H6 (CRMS32A x Mattatriveni) and H1 (CRMS31A x Jayathi) 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 form the standard check in most of the traits such as kernel length, kernel breadth, kernel length by breadth ratio, head rice recovery 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. Sathyan (2012) reported a cooking time of 29.33 minutes for the variety Jyothi which is another popular rice variety of Kerala. In this study, hybrids H4 (CRMS32A x Annapoorna), H6 (CRMS32A x Mattatriveni), H1 (CRMS31A x Jayathi), H5 (CRMS32A x Kanakom) had lower cooking time of around 25 minutes.

Lii *et al.* (1996) expressed that amylose content is considered as single most critical trait for cooking and handling conduct of rice. Hammaker and Griffin (1990) also reported that cooking and eating characteristics of rice is 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 'Uma'. Amylose content of hybrids H5 (CRMS32A x Kanakom) and H6 (CRMS32A x Mattatriveni) were on par with the standard check variety Uma. H4 (CRMS32A x Annapoorna) showed a higher value and H3 (CRMS31A x Remya), H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) showed a lower value of amylose content

Azabagaoglum *et al.* (2009) and Musa *et al.* (2011) disclosed that consumer inclination shifts in view of the kind of rice and their place of origin. Lyon *et al.* (2000) claimed that rice texture is an important pointer of rice quality as it influence acceptance of cooked rice by the purchasers. Keralites prefer non sticky bold to medium red kernelled rice with hard and dry texture from traditional period onwards. The amylose content of these hybrids shows that the cooking quality of the hybrids was on par with that of Uma. Aliwati (2003) reported that high amylose content give hard and dry texture to the cooked rice.

Volume expansion of H5 (CRMS32A x Kanakom) and H4 (CRMS32A x Annapoorna) were on par with that of variety Uma. Gelatinization temperature of all the hybrids except H1 (CRMS31A x Jayathi) and H5 (CRMS32A x Kanakom) were on par with that of Uma. H5 (CRMS32A x Kanakom) reported low while H1 (CRMS31A x Jayathi) exhibited high gelatinization temperature. This study has proven that the chemical qualities of the rice grains of the hybrids are acceptable to the consumers of Kerala as the values are similar to the most accepted commercial variety of Kerala 'Uma'.

Keralites are very specific for their preference to red kernel colour. Five out of six hybrids had kernel colour similar to Uma as shown in the Plate 5. H1 (CRMS31A x Jayathi) was as white as its male parent Jayathy was white kernelled. In this study it is seen that the hybrids inherit the kernel colour of the male parent or it may be assumed that red colour is dominant over white. But Vanaja (1998) concluded that pattern of inheritance of kernel colour in rice is a complex qualitative character. She additionally revealed that each red and white colour may be independently controlled by at least two sets of genes having both inhibitory and duplicate kind of gene interactions with predominance of inhibitory type gene interaction. By hybridization, , it was conceivable to effectively exchange the non sticky nature and red kernel colour of Mattatriveni to a high yielding Taiwan white kernelled rice variety and sticky on cooking.

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 (CRMS31A x Jayathi).The hybrids H1 (CRMS31A x Jayathi), H6 (CRMS32A x Mattatriveni) and H4 (CRMS32A x Annapoorna) had a grain shape of medium (Kernel length breadth ratio 2.1 to 3) even though the grains are slightly longer than that of Uma which is also a medium shaped variety The hybrids H3 (CRMS31A x Remya) and H5 (CRMS32A x Kanakom) registered the grain shape of female parent *i.e.,* long slender. Breadths of the kernel of all the hybrids except H1 (CRMS31A x Jayathi) were lower than that of Uma. This may be the reason for the phenomenon of curling noted in cooked rice of hybrids.

5.2.3. Standard Heterosis

All the hybrids showed non significant positive heterosis for yield plot^{-1}compared with that of Uma except H4 (CRMS32A x Annapoorna). In 1980, Lin and Yuan reported that the hybrids had lodging resistance better than their parents in spite of slightly taller stature. In this study also it was found that the hybrids were resistant to lodging despite its tall stature. Stiff root system and thicker culm of hybrids might be in charge for their resistance to lodging.

In the case of number of productive tillers, all the hybrids showed higher positive standard heterosis. H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) showed significant results for this trait. Joshi *et al.* (2004) reported that standard heterosis of number of tillers plant^{-1} ranged from -22.22 to 81.48. Increment in productive tillers was prior seen by Singh *et al.* (1980) and Anandakumar and

Sreerangasamy (1986), though Virmani *et al.* (1981, 1982) and Jennings (1967) detailed the negative heterosis for panicle number in the hybrids.

Only H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) showed significant heterosis (negative) for days to flowering compared with standard check Kanchana while all the other hybrids were late flowering than the short duration check. All the hybrids flowered within 63 to 87 days. According to Virmani (1982) the high yielding hybrids bloomed within 71 – 91 days demonstrating that growth duration did not confine the yield capability of hybrids and the hybrids tend to indicate more earliness than their parents. However their tallness was either practically identical or somewhat taller than their parents in the tropics in wet season. Two out of six hybrids were early maturing than the variety Kanchana. According to Virmani (1987), hybrids were seen to acquire varying growth duration which ranged from 105 to 136 days. The present study registered a duration ranging from 94 to 122 days.

Hybrid vigour for panicle length was seen in every one of the crosses however just the hybrids H4 (CRMS32A x Annapoorna), H5 (CRMS32A x Kanakom) and H6 (CRMS32A x Mattatriveni) demonstrated significant standard heterosis. Singh *et al.* (1980) detailed comparative outcomes. Significantly high value of standard heterosis was reported for the trait number of spikelets panicle^{-1} for all the hybrids except H1. Results got in China and at IRRI demonstrate that heterotic F_1 combinations normally indicated an increased sink dimension through an expansion in spikelet number panicle^{-1} (Virmani and Edwards, 1983).

For spikelet fertility percentage, no positive significant heterobeltiosis and standard heterosis were observed. Two hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) showed highly negative significant heterobeltiosis as well as standard heterosis for number of filled grains panicle^{-1}. According to Virmani *et al.* (1981), non significant positive or negative heterosis for number of filled grains panicle^{-1} can be noticed and he concluded that even though the hybrids had less effective panicles per square meter, they had significantly more number of filled grains panicles^{-1} and bigger seeds.

All the hybrids except H5 (CRMS32A x Kanakom) failed to give positive heterosis for fertility of pollen. Non significant positive or negative heterosis for this character was revealed by Virmani *et al.* (1981). Even though the number of spikelets panicle^{-1} was high, insufficient restoration of fertility paved the way to chaffiness of spikelets which in turn reduced the potential of hybrid to register further high number of filled grains pancle^{-1}. High number of ear bearing tillers plant^{-1} was observed in H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni), 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 is required for both panicles plant^{-1} and spikelet fertility simultaneously (Virmani *et al.*, 1981).

The higher length of grain for the hybrids paved the way to register significantly higher value of standard heterosis for length-breadth ratio of grain. All the hybrids except H3 (CRMS31A x Remya) registered negative heterosis for 1000 grain weight. Grain yield plant^{-1} showed almost same value of standard heterosis as that of yield plot^{-1}. The hybrids H1 (CRMS31A x Jayathi), H3 (CRMS31A x Remya) and H5 (CRMS32A x Kanakom) showed high estimated value of standard heterosis. Of these H2 (CRMS31A x Kanakom) and H5 (CRMS32A x Kanakom) have the common male parent Kanakom which shows that the variety Kanakom is a good combiner with the CMS line to give high heterosis for yield. Most crosses indicating significant standard heterosis for yield were observed to have heterosis for more than one component. None of the crossovers indicated heterosis for all the contemplated characters. Same outcomes were additionally detailed by Maurya and Sing (1978) and Virmani *et al.* (1982). Hence from the outcomes it is clearly indicated that hybrid vigour for yield is the consequence of association of synchronous increment in the expression of yield attributes.

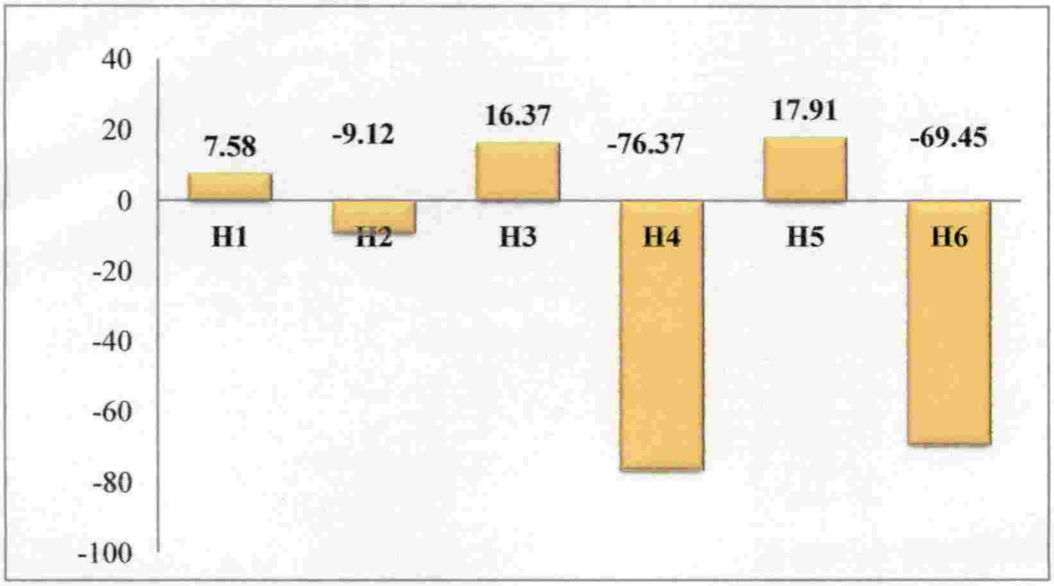


Fig. 5. Standard heterosis for yield over variety 'Uma'

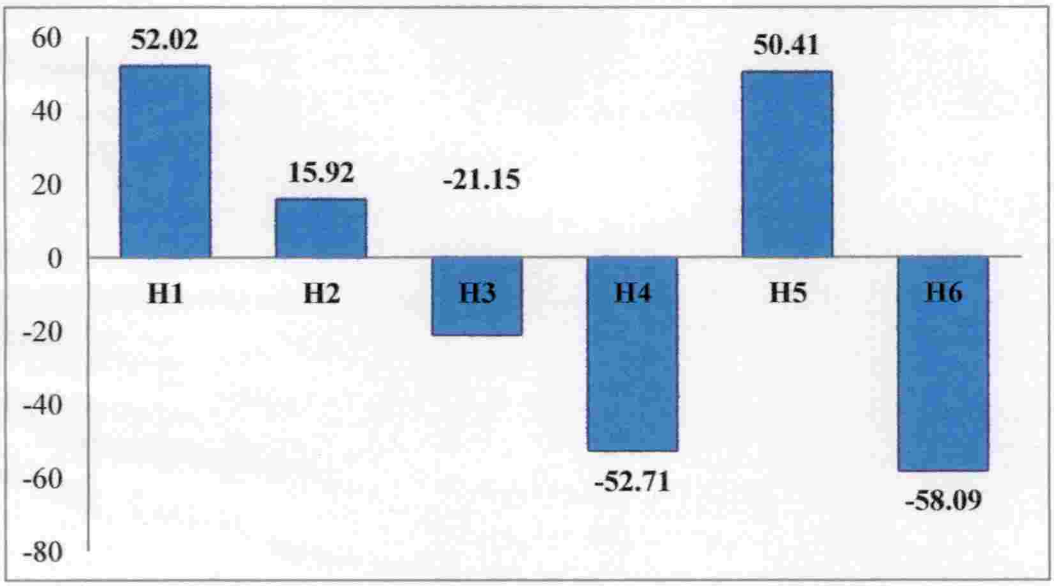


Fig. 6. Heterobeltiosis of hybrids over better parents

5.2.4. Heterobeltiosis

All the hybrids except H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) showed positive heterobeltiosis over the better parent (restorers). Most of the hybrids showed dwarfness compared to better parent. Hybrids tend to indicate more earliness than their parents but their height was either equivalent or marginally taller than their parents in the tropics in wet season (Virmani *et al.* 1982). Accordingly, plant tallness is a standout amongst the most vital components to control lodging. In rice, grain yield and plant tallness have a significant negative connection. In this experiment, negative heterobeltiosis for plant height was seen in most of the hybrids. Alam *et al.* (2004) and Nuruzzaman *et al.* (2002) likewise detailed negative heterobeltiosis for rice plant stature in a few crosses. While at the same time choosing genotypes for higher yield potential, accentuation ought to be given for nearly long vegetative period, brief period from panicle initiation to 50 % blooming and long maturing period (Vanaja, 1998). As per Virmani *et al.* (1982), earliness does not influence yield capability of the hybrid.

Even if the highest number of productive tillers was observed for H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni), they can't contribute much to yield since chaff amount was high. All the hybrids flowered earlier than their parents hence exhibiting hybrid vigour over the better parent.

Except H1 (CRMS31A x Jayathi) all the hybrids showed positive heterobeltiosis for panicle length, which is a yield contributing character. Most of the hybrids failed to show significant positive heterobeltiosis for pollen fertility. All the hybrids could exhibit positive heterobeltiosis for number of spikelets panicle^{-1}. Positive heterobeltiosis over better parent and standard variety was observed by Virmani *et al.* (1981, 1982) and they presumed that heterobeltiosis in yield was basically because of increased number of spikelets panicle^{-1}. Hybrids showed earliness in maturity. Heterobeltiosis in hybrids were seen to posses varying growth duration extending from 105 to 136 days (Virmani., 1987).

Except H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) all the others showed positive heterobeltiosis for number of filled grains panicle^{-1}. The number of fertile spikelets specifically adds to seed yield subsequently positive heterotic impact would be highly desirable. The fruitful usage of CMS in development of hybrids isn't conceivable except if the effective restorer lines are recognized. In the present investigation, more number of fertile spikelets is nearly connected with high yield plant^{-1} bringing about high productivity. In this manner, the prime interest is to discover the cross combinations with more number of long and heavy panicle bearing tillers with more number of filled grains. Heterobeltiosis as for 100 grain weight in positive and negative direction have likewise been accounted by Virmani *et al.* (1981), Srivastava and Seshu (1982), Vikratamah (1987), Manual and Palanisami (1989), Sharma and Mani (1990) Wilfred and Prasad (1992), and Lokprakash *et al.* (1992). Four out of six hybrids showed positive length breadth ratio of grain since they are longer than their parents. H1 (CRMS31A x Jayathi) and H5 (CRMS32A x Kanakom) showed significant positive heterobeltiosis for yield plot^{-1}. Grain yield showed highly significant heterobeltiosis and standard heterobeltiosis in five crosses. Heterobeltiosis ranging from –55 to 139 % and standard heterobeltiosis from –11 to 369 % were also registered (Joshi, 2001).

Cooking time was comparatively less than restorers. Volume expansion was also higher than parents. The hybrids H5 (CRMS32A x Kanakom) and H6 (CRMS32A x Mattatriveni) showed negative heterobeltiosis for this character. Kernel length showed positive heterobeltiosis. Except H1 (CRMS31A x Jayathi), all others showed a lesser heterobeltiosis for kernel breadth. Hybrids H1 (CRMS31A x Jayathi) and H5 (CRMS32A x Kanakom) recovered more during milling. Hybrids H1 (CRMS31A x Jayathi) and H4 (CRMS32A x Annapoorna) showed positive heterobeltiosis for amylose content. All the hybrids could acquire more or more characters of the restorers with respect to quality parameters. Similar results were reported by Vanaja (1998).

Hybrids H1 (CRMS31A x Jayathi), H3 (CRMS31A x Remya) and H5 (CRMS32A x Kanakom) showed 7.58%, 16.37% and 17.91% yield advantage respectively over standard check variety Uma (Fig. 5). Hybrids H1 (CRMS31A x Jayathi) and H5 (CRMS32A x Kanakom) gave a heterobeltiosis of 52.02% and 50.41% respectively (Fig. 6). But the pollen fertility of H1 hybrid was only 50 so it cannot be recommended.

This evaluation of hybrids could identify two promising hybrids for Kerala H5 (CRMS32A x Kanakom) and H3 (CRMS31A x Remya) with 17.91 and 16.37% yield advantage over the popular rice variety Uma respectively. According to Virmani (1996), varieties of hybrid rice with a yield increment of 15-20 % over the traditional 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. 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.

SUMMARY

6. SUMMARY

Rice (*Oryza sativa* L.) is a major food grain crop and staple food of Kerala. It is considered as the worlds' most diverse cereal crop. The demand of rice continues to rise in Kerala because of increase in population and improvement in living standards. Keralites are strict in their preference to quality aspects of rice. It is one of the rare places where the people prefer red kernelled bold rice types.

The present study entitled "Evaluation of CMS based rice hybrids developed from rice varieties of Kerala identified as restorers" was carried out with an objective to evaluate CMS based rice hybrids developed from rice varieties of Kerala as restorers, for heterosis for yield and grain quality. The study was conducted in two experiments *i.e.*, 1) Hybrid seed production, 2) Evaluation of hybrids

Two CMS lines *viz.*, CRMS31A and CRMS32A were crossed with nine restorers. Restorers were sown in three staggers; 10 days before the sowing date of CMS lines, at the sowing date of CMS lines and 10 days after the sowing date of CMS lines. Synchronized flowering dates of the CMS and restorer lines were recorded. CRMS31A was crossed with Remya, Jayathy, Swarnaprabha, Kanakom and Neeraja. CRMS32A was crossed with Annapoorna, Aiswarya, Mattatriveni and Kanakom. Six crosses *i.e.*, CRMS31A x Jayathi (H1), CRMS31A x Kanakom (H2), CRMS31A x Remya (H3), CRMS32A x Annapoorna (H4), CRMS32A x Kanakom (H5), CRMS32A x Mattatriveni (H6) that had given more than about 1500 viable seeds were carried forward for hybrid evaluation. Date of sowing of the restorers and maintainers for getting synchronization in flowering to undertake hybridization was standardized in this experiment.

In the second experiment, hybrids along with checks were evaluated in a Randomized Block Design (RBD) with three replications. Observations on twelve yield contributing traits and eight grain quality traits were recorded in the hybrids. Genetic parameters calculated from these observations showed that the GCV and

PCV values for the characters studied did not vary greatly, indicating low influence of the environment in these characters.

The mean performance of hybrids showed that the yield plot^{-1} was highest for H5 (CRMS32A x Kanakom) followed by H3 (CRMS31A x Remya), H1 (CRMS31A x Jayathi), H2 (CRMS31A x Kanakom), H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni). The hybrid H5 (CRMS32A x Kanakom) showed the highest mean values for plant height, number of filled grains panicle^{-1}, length-breadth ratio of grain and grain yield (g) plant^{-1}. The thousand grain weight was lower for all the hybrids except H3 (CRMS31A x Remya) but this trait of H2 (CRMS31A x Kanakom) was on par with that of Uma.

Pollen fertility of the hybrid H5 (CRMS32A x Kanakom) was superior to the standard check. This shows that the variety Kanakom is a complete restorer for male sterile cytoplasm CRMS32A. Hybrid H3 (CRMS31A x Remya) also showed pollen fertility on par with the check showing that the variety Remya is restorer for CRMS31A. The other hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) had pollen fertility per cent around 50. So the male parents Annapoorna and Mattatriveni for CRMS32A can be considered as only partial restorers. The low level of pollen fertility was the reason for low yield of hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) despite high number of productive tillers.

For days to maturity, the hybrids H1 (CRMS31A x Jayathi) and H2 (CRMS31A x Kanakom) were on par with that of Uma where as the hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) matured earlier than the standard check Kanchana. The male parent of hybrid H4 (CRMS32A x Annapoorna) was Annapoorna which is a short duration variety. From this evaluation of hybrids it is seen that the duration of male parent decided the duration of hybrids. The low level of pollen fertility was the reason for low yield of hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) despite high number of productive tillers.

Five out of six hybrids were red kernelled. It was found that the hybrids inherited the kernel colour from the male parents. H1 (CRMS31A x Jayathi) was white as its male parent Jayathy was also white kernelled. The kernel lengths by breadth ratio of all the hybrids were significantly higher than that of Uma. The hybrids had a medium to slender grain shape (kernel length by breadth ratio 2.1 to 3 and above). This may be the reason behind the phenomenon of curling noted in cooked rice in all the rice hybrids studied. Most of the hybrids were in the class intermediate (as per SES manual) along with that of that of the standard check showing the hard and non sticky nature of the cooked rice of the hybrids. The amylose contents of most the hybrids shows that the cooking quality of the hybrids was on par with that of Uma. Cooking time for hybrids was less (25 minutes) compared to that of Uma (29 minutes). Hence this study has proven that the chemical qualities of the rice grains of the hybrids are acceptable to the consumers of Kerala as the values are similar to the most accepted commercial variety of Kerala 'Uma'.

Standard heterosis for yield plot^{-1}of the hybrids calculated over the standard check variety Uma was highest for H5 (CRMS32A x Kanakom) followed by H3 (CRMS31A x Remya) and H1 (CRMS31A x Jayathi). Heterobeltiosis for yield calculated over the better parent was high for H1 (CRMS31A x Jayathi) followed by H5 (CRMS32A x Kanakom). Only H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) showed significant negative heterosis for days to flowering compared with standard check Kanchana while all the other hybrids were late flowering than the short duration check. Hybrid vigor for panicle length was noticed in all the crosses but only the hybrids H4 (CRMS32A x Annapoorna), H5 (CRMS32A x Kanakom) and H6 (CRMS32A x Mattatriveni) showed significant standard heterosis. There were no positive significant heterobeltiosis and standard heterosis for spikelet fertility percentage. Two hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) showed highly negative significant heterobeltiosis and standard heterosis for number of filled grains panicle^{-1}. High number of ear bearing tillers plant^{-1} was observed in H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni), 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. The higher length of grain for the hybrids paved the way to register significantly higher value of standard heterosis for length breadth ratio of grain. All the hybrids except H3 (CRMS31A x Remya) registered negative heterosis for 1000 grain weight. Grain yield plant^{-1} showed almost same value of standard heterosis as that of yield plot^{-1}. The hybrids H1 (CRMS31A x Jayathi), H3 (CRMS31A x Remya) and H5 (CRMS32A x Kanakom) showed high estimated value of standard heterosis. Of these H2 (CRMS31A x Kanakom) and H5 (CRMS32A x Kanakom) have the common male parent Kanakom which shows that the variety Kanakom is a good combiner with the CMS line to give high heterosis for yield. Most crosses with significant heterosis for yield were found to be having heterosis for more than one component trait. None of the hybrids showed heterosis for all the studied characters.

This evaluation of hybrids could identify two promising hybrids for Kerala H5 (CRMS32A x Kanakom) and H3 (CRMS31A x Remya) which could give a yield advantage of 17.91% and 16.37% 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. Hence the hybrids can be recommended for Kerala after trials over locations and seasons. A better seed production technique has to be standardized before commercial release.

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Evaluation of CMS based rice hybrids developed from rice varieties of Kerala identified as restorers

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ABSTRACT

The present study entitled "Evaluation of CMS based rice hybrids developed from rice varieties of Kerala identified as restorers" was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2016-2018, with an objective to evaluate CMS based rice hybrids developed from rice varieties of Kerala as restorers, for heterosis for yield and grain quality. The study was conducted in two experiments *i.e.*, 1) Hybrid seed production 2) Evaluation of hybrids. The first experiment, on hybrid seed production was undertaken in College of Agriculture, Vellayani during May to August, 2017 (*Virippu, 2017)*.

Two CMS lines *viz*., CRMS31A and CRMS32A were crossed with nine restorers. Restorers were sown in three staggers, 10 days before the sowing date of CMS lines, at the sowing date of CMS lines and 10 days after the sowing date of CMS lines. Synchronized flowering dates of the CMS and restorer lines were recorded. CRMS31A was crossed with Remya, Jayathy, Swarnaprabha, Kanakom and Neeraja. CRMS32A was crossed with Annapoorna, Aiswarya, Mattatriveni and Kanakom. Six crosses *i.e.,* CRMS31A x Jayathi (H1), CRMS31A x Kanakom (H2), CRMS31A x Remya (H3), CRMS32A x Annapoorna (H4), CRMS32A x Kanakom (H5), CRMS32A x Mattatriveni (H6) that had given more than 1500 viable seeds were carried forward for hybrid evaluation. Date of sowing of the restorers and maintainers for getting synchronization in flowering to undertake hybridization was standardized in this experiment.

In the second experiment, hybrids along with the better parent and checks were evaluated in a Randomized Block Design (RBD) with three replications during October 2017 to February 2018 *(Mundakan)* in IFSRS (Integrated Farming System Research Station), Karamana.

Observations on 12 yield contributing traits and 8 grain quality traits were recorded in the hybrids. Genetic parameters calculated from these observations

showed that the GCV and PCV values for the characters studied did not vary greatly indicating low influence of the environment in these characters.

The mean performance of hybrids showed that the yield plot $^{-1}$ was the highest for H5 (CRMS32A x Kanakom) followed by H3 (CRMS31A x Remya), H1 (CRMS31A x Jayathi), H2 (CRMS31A x Kanakom) and H4 (CRMS32A x Annapoorna). The hybrid H5 (CRMS32A x Kanakom) showed the highest mean values for plant height, number of filled grains panicle^{-1}, length breadth ratio of grain and grain yield (g) plant^{-1}. Pollen fertility of the hybrid H3 (CRMS31A x Remya) was superior to the standard check. This shows that the variety Remya is a complete restorer for male sterile cytoplasm CRMS31A. Hybrid H5 also showed pollen fertility on par with the check showing that the variety Kanakom is restorer for CRMS32A. The other hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) had pollen fertility per cent around 50. So the male parents Annapoorna and Mattatriveni for CRMS32A can be considered as only partial restorers. The low level of pollen fertility was the reason for low yield of hybrids H4 (CRMS32A x Annapoorna) and H6 (CRMS32A x Mattatriveni) despite high number of productive tillers.

Five out of six hybrids were red kernelled. It was found that the hybrids inherited the kernel colour from the male parents. The kernel length by breadth ratio of all the hybrids was significantly higher than that of Uma. The hybrids had a medium to slender grain shape (kernel length by breadth ratio 2.1 to 3 and above). This may be the reason behind the phenomenon of curling noted in cooked rice in all the rice hybrids studied.

Standard heterosis for yield plot^{-1}of the hybrids calculated over the standard check variety Uma was the highest for H5 (CRMS32A x Kanakom) followed by H3 (CRMS31A x Remya) and H1 (CRMS31A x Jayathi). Heterobeltiosis for yield calculated over the better parent was maximum for H1 (CRMS31A x Jayathi) followed by H5 (CRMS32A x Kanakom). Amylose content of most of the hybrids fell into intermediate category along with that of the check variety Uma, showing the hard and non sticky nature of the cooked rice of the hybrids. Cooking time for hybrids was less compared to that of Uma (29 minutes).

This evaluation of hybrids could identify two promising hybrids for Kerala H5 (CRMS32A x Kanakom) and H3 (CRMS31A x Remya) which could give a yield advantage of 17.91% and 16.37% 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. Hence the hybrids can be recommended for Kerala after trials over locations and seasons. A better seed production technique has to be standardized before commercial release.