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Research Article

Inheritance studies in red kernel rice (*Oryza sativa* L.)

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Abstract
Inheritance of red kernel and hull colour were studied in eight crosses between white kernel/red kernel rice varieties *viz.*, Karjat 4/Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Ratnagiri 5/TKM 9, Karjat 184/Munga, Karjat 6/Bela, Ratnagiri 24/Valai and Karjat 8/MO 8 during *rabi* 2013-14 using their parents, F_1's, F_2's and BC_1, BC_2 populations. Segregation pattern reveled that red kernel in rice is governed by one dominant gene in six crosses fitting the F_2 chi square ratio 3:1 while as it was governed by two dominant gene in two crosses exhibiting F_2 chi square ratio 9:7 which indicated complementary type of gene action and were confirmed in BC_1F_1 fitting chi square ratio 1:1 red kernel to white kernel ratio. The inheritance pattern of hull colour in six crosses; brown hull colour was dominant over straw hull colour; governed by two independent genes, one dominant and one recessive gene fitting F_2 chi square ratio 13:3. Similarly, in two other crosses, brown hull colour was dominant over golden yellow and yellow hull colour fitting F_2 chi square ratio 9:7 and governed by two dominant gene with complementary type gene action. The inheritance studies of red kernel rice are very important to bred biofortified rice varieties.

Key words
Inheritance, Red Kernel, husk colour, chi square

Introduction

Rice is a major food staple and energy source for more than half of the world population, (Lucca *et al.*, 2002) being the major source of carbohydrate. However, rice is a poor source of essential micronutrients such as Fe and Zn. Micronutrient malnutrition, and particularly Fe and Zn deficiency affect over three billion people worldwide, mostly in developing countries (Bouis and Welch, 2010). Production of varieties containing high amounts of bioavailable Fe would help alleviate iron deficiency. It is necessary to improve both the net Fe & Zn concentration and their bioavailability in rice grain for improving the Fe & Zn intake in populations dependent on rice as a staple food (Mehansho, 2006). Food fortification has been recommended as one of the preferred approaches for preventing and eradicating iron and zinc deficiency. Biofortification, when applied to a staple crop, such as rice is a sustainable approach, provided that access to the technology in the form of seeds is unrestricted (Meng, 2005).

In some areas of India, red rice are considered highly nutritive and medicinal. The rice is eaten as whole grain; Red gunja is preferred for making bread and *chapati*. Glutinous rice is used in making *puttu* in South India. In Himachal Pradesh, Jatu red rice is prized for its aroma and taste. Matali and Laldhan of Himachal Pradesh are used for curing blood pressure and fever. Kafalya, from the hills of Himachal Pradesh and Uttar Pradesh, is used for treating leucorrhea and abortion complications. Karikagga and Atikaya of Karnataka are used for coolness and as tonic, while Neelamsamba is used for lactating mothers in Tamil Nadu (Arumugasamy *et al*., 2001).

In Maharashtra, particularly in Sindhudurg, Ratnagiri, Raigad and Thane districts, local red kernel types are grown since ancient years. These varieties are Patni, Munga, Bela, Valai, Halga Red, Kala Rata, Bura Rata, Jaddu, Varangal etc. These local red rices are mainly having bold grain type, tall and grassy stature, seed dormancy, sparse plant type, lodging and low yields. However, these varieties are having low amylose, high zinc, iron, riboflavin and antioxidant properties (Deshpande *et al.*, 2004). Their nutritional and physico-chemical properties are used for making soup; locally known as *Pej* and served to children, women and patients for their daily breakfast.

Red colour is dominant over white kernel colour. The inheritance of red colour is monogenic (Nagao *et al.*, 1963, Sastry, 1978, Kinoshita 1995, Thomar *et al.*, 2000 Bres-patry *et al.* 2001, Gealy *et al.*, 2006, Han *et al.*, 2006, Hemprabha *et. al.*, 2007 and Shahu *et al.*, 2009) inheritance of red kernel in same genotypes are digenic (Bres-patry *et al.* 2001, Hemprabha *et al.*, 2007) Brown hull colour is dominant over straw and golden had colour two independent genes, one dominant and one recessive gene responsible for hull colour (Nagao *et al.*, 1963, Shahu *et al.*, 2009).

Considering these attributes, red rice could once again find favour with health conscious consumers. It is high time that people in India took a fresh look at similar properties in the vast pool of indigenous red rice. So there is a need for revival of red rice in

India and hence the development of newer cultivars. There is also a dire need for clinical validation of the medicinal value of red rice reported in ancient literature, and for research on food preparations from red rice. Hence, the efforts being made to study the genetic basis and physico-chemical properties of red kernel rice cultivars. Attempts have been made by different workers to find out the relationship between different genes governing different characters in rice and their inheritance pattern to the progeny.

Material and Methods

The investigation comprised of seven red kernel *viz.*, Patni 6, MO 17, MO 8, TKM 9, Munga, Bela and Valai used as males parents and eight white kernel fine rice cultivars *viz*, Karjat 4, Panvel 2, Palghar 1, Ratnagiri 5, Karjat 184, Karjat 6, Ratnagiri 24 and Karjat 8 used as females all were collected from Agricultural Research Station, Shirgaon, Ratnagiri (Dr. B. S. Konkan Krishi Vidyapeeth) (MS), India.

Eight crosses between White/Red rice cultivars were effected during *Rabi* 2012-13. F_1s were grown during *Kharif* 2013 and F_2 seeds of each cross were obtained. The BC_1 and BC_2 crosses were effected during *Kharif* 2013. The parents, F_1s, F_2s, BC_1s and BC_2s were evaluated during *Rabi* 2013-14. Parents, F_1s, F_2s, BC_1s, BC_2s seeds were sown for raising the nursery in plastic pots. The seedlings of 21 days age were transplanted in two rows of 15 plants each of parents and F_1s and all populations of F_2s, BC_1s and BC_2s in the main field at the spacing 20 x 15 cm during *Rabi* 2013-14 for evaluation at experimental farm Agricultural Research Station, Shirgaon (MS), India.

The data of different characters was recorded on Plant count of red kernel plants, Red kernels panicle^{-1}, Colour of hull, Grain yield plant^{-1}(g). One panicle taken from selected five plants of all F_1s and F_2s and observed total kernels for its redness or whiteness in whole panicle.

The expected values corresponding to the observed values for each characters were calculated based on the presumed ratio. The deviations were put to X^2 test (Fisher, 1936).

Results and Discussion

Inheritance of red kernel colour: The inheritance of red kernel colour in rice and the relationship of the genes controlling the characters were worked out in 8 crosses in rice. The details of kernel colours of parents and their F_1s are given in table 1. There were eight crosses effected by using eight white kernel female *viz.*, Karjat 4, Panvel 2, Palghar 1, Ratnagiri 5, Karjat 184, Karjat 6, Ratnagiri 24 and Karjat 8 with seven red kernel male parents *viz.*, Patni 6, MO 17, MO 8, TKM 9, Munga, Bela and Valai. The F_1 plants were observed for the kernel colours and it was observed that the F_1 progenies of all crosses were having red kernels (Table 2). It showed that the red kernel colour is dominant over white kernel colour. This character indicated dominant type of expression. This is in consonance with the findings of Nagao *et al.* 1963, Sastry 1978, Kinoshita 1995, Tomar *et al.* 2000, Bres-Patry *et al.* 2001, Gealy *et al*. 2006, Han *et al.* 2006; Hemprabha *et al.* 2007 and Sahu *et al.* 2009.

The segregation pattern of the progenies of the crosses between white kernel and red kernel colour in F_2 generation is presented in Table 3. The mode of inheritance of red kernel colour was studied in eight crosses *viz.*, Karjat 4 /Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Ratnagiri 5/TKM 9, Karjat 184 /Munga, Karjat 6 /Bela, Ratnagiri 24 /Valai and Karjat 8/MO 8. The proportion of plants with red and white kernel colour in F_2 population closely fitted in the ratio of 3 : 1 for six crosses *viz.*, Karjat 4 /Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Karjat 184 /Munga, Ratnagiri 24 /Valai, Karjat 8/MO 8. This indicated that red colour of kernel in the varieties Patni 6, MO 17, MO 8, Munga and Valai was governed by single dominant gene. This was confirmed by observing the segregation pattern of the progenies obtained from the backcrosses (test crosses) between red F_1s and white kernel parents given in Table 4. Red F_1 progenies of eight crosses were backcrossed/test crossed their respective parents i.e. white kernel parents. The proportion of red and white kernel plants in BC_1 F_1s data of six crosses *viz.*, Karjat 4 /Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Karjat 184 /Munga, Ratnagiri 24 /Valai and Karjat 8/MO 8 were closely fitted in 1 : 1 Chi Square Ratio. This confirmed the monogenic inheritance of red kernel colour. It clearly indicated that red kernel colour was dominant character over white kernel colour and this trait was governed by one major dominant gene.

However in two crosses *viz.*, Ratnagiri 5/TKM 9 and Karjat 6 /Bela the proportion of plants with red and white kernel colour in F_2 population closely fitted in the ratio of 9:7. This also confirm with BC_1 F_1 evaluation data of red and white kernel plants in these crosses closely fitted to 1:3 ratio (Table 4). It indicated the two genes controlling the red kernel colour in these crosses. It seems complementary type of gene interaction having joint effect of both the genes for expression of red kernel colour. These two major genes either of them complementing with other dominant gene, to be responsible for this trait. This is duplicate recessive epistasis type of interaction found for expression of the red kernel colour as dominant Bres-Patry *et al.* (2001). This is in accordance with the findings of Kinoshita (1995) and Hemprabha *et al.* (2007) and Bres-Patry *et al.* (2001). They confirmed that this trait was controlled by two complementary genes in rice.

The segregation pattern of the progenies obtained from the BC_2 F_1 backcross (Test crosses) between red F_1s and red kernel parents are presented in Table 5. The red F_1 progenies of eight crosses *viz.*, Karjat 4/ Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Ratnagiri 5/TKM 9, Karjat 184/ Munga, Karjat 6/ Bela, Ratnagiri 24/ Valai and Karjat 8/MO 8 were backcrossed with their respective red kernel parents. The evaluation of BC_2 F_1 progenies showed all red plants in all the eight crosses studied. It means that red kernel colour was completely dominant over white colour. It might be controlled by monogenically or digenically. Nagao *et al.* (1963) reported similar gene action and designated the gene as *Rd.* Sastry (1978) and Sahu (1991) also reported similar gene action for the red pericarp in rice. Gealy *et al.* (2006) observed that F_2 progenies of white rice/red rice cross segregated in ratios of approximately 3 red: 1 white seed colouration, consistent with single dominant gene control of this trait. Han *et al.* (2006) also confirmed that, the red seed colour phenotype resulted from a monogenic dominant character.

Inheritance of rice hull colour: The segregation pattern of the progenies of the crosses between different hull colours in F_2 generation (Table 6). In the crosses *viz.*, Karjat 4/Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Ratnagiri 5/TKM 9, Ratnagiri 24/Valai and Karjat 8/MO 8 having female parent with straw hull colour and male parent with brown colour hull; it was observed that all the F_1 plants were having brown hull colour. This indicated that brown hull colour was dominant over straw hull colour. These F_1 progenies were observed in F_2 generation for hull colour. The proportion of plants with brown and straw hull colour in F_2 population closely fitted in the ratio of 13:3 indicating the action of two independent genes, one dominant and other one recessive responsible for expression of hull colour. Similar results were reported by Nagao *et al.* (1963) and Sahu *et al.* (2009). While, Sahu *et al.* (2009) designated these genes as Pr-1 and pr-2.

In the cross Karjat 184/Munga having female parent with golden hull colour and male parent with brown hull colour, it was observed that all the F_1 plants were having brown hull colour. This indicated that brown hull colour was dominant over golden hull colour. These F_1 progenies were observed in F_2 generation for hull colour. The proportion of plants with brown and golden hull colour in F_2 population closely fitted in the ratio of 9:7 indicating the action of two major genes either of them complementing with other dominant gene responsible for expression of hull colour. While as in cross Karjat 6/Bela having female parent with yellow hull colour and male parent with brown hull colour, it was observed that all the F_1 plants were having brown hull colour. This indicated that brown hull colour was dominant over yellow hull colour. These F_1 progenies were observed in F_2 generation for hull colour. The proportion of plants with brown and yellow hull colour in F_2 population closely fitted in the ratio of 9:7 indicating the action of two major genes either of them complementing with other dominant gene responsible for expression of hull colour. Similar results were reported by and Sahu *et al.* (2009).

Eight crosses between white kernel/red kernel rice cultivars were effected to study the genetic basis of red Kernel of rice. Zinc and Iron content of red rice is 2-3 times higher than that of white rice (Ramaiah and Rao, 1953, Rood 2000). In all of the eight crosses the red kernel colour was found to be dominant over the white kernel colour and the trait was under monogenic control in six crosses *viz.*, Karjat 4/Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Karjat 184/Munga, Ratnagiri 24/Valai and Karjat 8/MO 8 and under digenic control in the other two crosses *viz.*, Ratnagiri 5/TKM 9 and Karjat 6/Bela,. Similarly in case of hull colour, the brown hull colour was dominant over the other hull colours under study *viz.*, straw, golden and yellow in crosses Karjat 4/Patni 6, Panvel 2/MO 17, Palghar 1/MO 8, Ratnagiri 5/TKM 9, Ratnagiri 24 /Valai and Karjat 8/MO 8 over straw hull colour, in cross Karjat 184/Munga over golden hull colour and in Karjat 6/Bela cross over yellow hull colour respectively.

This inheritance studies are very important for selection of the red kernel parents with high Zinc and Iron content for breeding biofortified rice varieties some of the red kernel local land races found in Konkan region are rich in antioxidant, iron, Zinc content, and low glycemic index. Zinc and Iron content of red rice is 2-3 times higher than that of white rice (Ramaiah and Rao, 1953, Rood 2000).

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Table 1. Details of kernel colours of the parents and their hybrids

Cross. No.	Name of cross	P_1/P_2	Number of plants grown in F_1	Kernel colour in F_1		F_1 phenotype
				Red	White	
1	Karjat 4/Patni 6	White/Red	32	32	0	All Red
2	Panvel 2/MO 17	White/Red	30	30	0	All Red
3	Palghar 1/MO 8	White/Red	29	29	0	All Red
4	Ratnagiri 5/TKM 9	White/Red	31	31	0	All Red
5	Karjat 184/Munga	White/Red	28	28	0	All Red
6	Karjat 6/Bela	White/Red	30	30	0	All Red
7	Ratnagiri 24/Valai	White/Red	29	29	0	All Red
8	Karjat 8/MO 8	White/Red	28	28	0	All Red

Table 2. Average grain counts for red and white kernels in F_1 and F_2 generations

Sr. No.	Name of cross		Average grains panicle^{-1}	Red kernels panicle^{-1}	White kernel panicle^{-1}	Remarks
1	Karjat 4/Patni 6	F_1	107	107	0	All red
		F_2	121	121	0	All red
2	Panvel 2/MO 17	F_1	98	98	0	All red
		F_2	104	104	0	All red
3	Palghar 1/MO 8	F_1	110	110	0	All red
		F_2	136	136	0	All red
4	Ratnagiri 5/TKM 9	F_1	89	89	0	All red
		F_2	129	129	0	All red
5	Karjat 184/Munga	F_1	94	94	0	All red
		F_2	114	114	0	All red
6	Karjat 6/Bela	F_1	91	91	0	All red
		F_2	128	128	0	All red
7	Ratnagiri 24/Valai	F_1	115	115	0	All red
		F_2	123	123	0	All red
8	Karjat 8/MO 8	F_1	106	106	0	All red
		F_2	131	131	0	All red

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Table 3. Segregation pattern of the progenies of the crosses between white kernel and red kernel colour in F_2 generation

Cross No.	Name of cross	P_1/P_2	F_1 Phenotypes	F_2 observations		X^2 ratio	X^2 value	P value
				Red	White			
I	Karjat 4/Patni 6	White/Red	Red	1372	492	3:1	1.93	0.20-0.10
II	Panvel 2/MO 17	White/Red	Red	1521	539	3:1	1.49	0.30-0.20
III	Palghar 1/MO 8	White/Red	Red	1440	501	3:1	0.68	0.50-0.30
IV	Ratnagiri 5/TKM 9	White/Red	Red	939	701	9:7	0.67	0.50-0.30
V	Karjat 184/Munga	White/Red	Red	1576	543	3:1	0.44	0.70-0.50
VI	Karjat 6 /Bela	White/Red	Red	1061	784	9:7	1.18	0.30-0.20
VII	Ratnagiri 24/Valai	White/Red	Red	1431	439	3:1	2.31	0.20-0.10
VIII	Karjat 8/MO 8	White/Red	Red	1548	541	3:1	0.89	0.50-0.30

Table value at 1 d.f. and 0.05% level of significance = 3.84

Table 4. Segregation pattern of the progenies obtained from the backcrosses (testcrosses) of red F_1s with white kernel parents (BC_1F_1)

Cross No.	Name of cross	P_1/P_2	BC_1F_1 observations		X^2 ratio	X^2 value	P value
			Red	White			
I	Karjat 4 /Patni 6 //Karjat 4	Red/White	42	49	1 : 1	0.54	0.50-0.30
II	Panvel 2/MO 17 //Panvel 2	Red/White	40	55	1 : 1	2.37	0.20-0.10
III	Palghar 1/MO 8 //Palghar 1	Red/White	47	58	1 : 1	1.14	0.30-0.20
IV	Ratnagiri 5/TKM 9 //Ratnagiri 5	Red/White	29	69	1 : 3	1.10	0.30-0.20
V	Karjat 184 /Munga //Karjat 184	Red/White	48	36	1 : 1	1.71	0.20-0.10
VI	Karjat 6 /Bela //Karjat 6	Red/White	30	65	1 : 3	2.19	0.20-0.10
VII	Ratnagiri 24 /Valai //Ratnagiri 24	Red/White	54	44	1 : 1	1.02	0.50-0.30
VIII	Karjat 8/MO 8 //Karjat 8	Red/White	45	31	1 : 1	2.58	0.20-0.10

Table value at 1 d.f. and 0.05% level of significance = 3.84

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Table 5. Segregation pattern of the progenies obtained from the backcrosses of Red F_1s with Red kernel parents (BC_2F_1)

Cross No.	Name of cross	P_1/P_2	BC_2F_1 observations		Remarks
			Red	White	
I	Karjat 4/Patni 6 // Patni 6	Red/Red	84	0	All Red
II	Panvel 2/MO 17 // MO17	Red/Red	112	0	All Red
III	Palghar 1/MO 8 // MO8	Red/Red	93	0	All Red
IV	Ratnagiri 5/TKM 9 // TKM9	Red/Red	75	0	All Red
V	Karjat 184 /Munga // Munga	Red/Red	76	0	All Red
VI	Karjat 6/Bela // Bela	Red/Red	92	0	All Red
VII	Ratnagiri 24/Valai // Valai	Red/Red	62	0	All Red
VIII	Karjat 8/MO 8 // MO 8	Red/Red	85	0	All Red

Table 6. Segregation pattern of the progenies of the crosses between different hull colours in F_2 generation

Cross No.	Name of cross	P_1/P_2	F_1 Phenotypes	Number of plants observed in F_2		X^2 ratio	X^2 value	P value
				Brown	**Straw**			
I	Karjat 4/Patni 6	Straw/Brown	Brown	1487	377	13 : 3	2.66	0.20-0.10
II	Panvel 2/MO 17	Straw/Brown	Brown	1693	367	13 : 3	1.18	0.30-0.20
III	Palghar 1/MO 8	Straw/Brown	Brown	1553	388	13 : 3	1.96	0.20-0.10
IV	Ratnagiri 5/TKM 9	Straw/Brown	Brown	1348	292	13 : 3	0.96	0.50-0.30
				Brown	**Golden**			
V	Karjat 184/Munga	Golden/Brown	Brown	1211	908	9 : 7	0.69	0.50-0.30
				Brown	**Yellow**			
VI	Karjat 6/Bela	Yellow/Brown	Brown	1022	823	9 : 7	0.55	0.50-0.30
				Brown	**Straw**			
VII	Ratnagiri 24/Valai	Straw/Brown	Brown	1502	368	13 : 3	1.06	0.50-0.30
VIII	Karjat 8/MO 8	Straw/Brown	Brown	1712	377	13 : 3	0.67	0.50-0.30

Table value at 1 d.f. and 0.05% level of significance = 3.84