Development of Rice Mutant Variety with Higher Yield and Improved Agronomic Traits through Carbon Ion Beam Irradiation

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Summary

BINA dhan14 is becoming more popular to the farmers due to the advantage of higher yield, early maturity, long grain fine rice and less water requirement over parent as it is cultivated in rain-fed condition. Advanced promising mutant line obtained from BRRI dhan 29 was released as a variety called BINA dhan18 and BINA dhan19 was developed from NERICA10. These varieties were developed through carbon ion beam irradiation from the QST, Takasaki, Japan with kind cooperation of FNCA during the period of late 2013 to early 2018. The main criteria of these varieties are lodging resistant with higher yield, long grain fine rice. BINA dhan14 is cultivated during Boro and Aus season, BINA dhan18 is moderate duration with higher yield Boro rice and BINA dhan19 is highly drought tolerant and also cultivated round the year. BINA dhan18 is about 100 cm tall and requires 148-153 days (seed to seed) to mature. Maturity was observed 13-15 days earlier than that of the parent variety BRRI dhan29. Thousand grain weight is about 26.5 g, amylose and protein contents are 23.2% and 7.06%, respectively. The average yield of 7.25 t/ha and the highest yield of 10.5 t/ha was recorded in favorable environmental condition. The average yield of BINA dhan19 is about 3.84 t/ha and the maximum yield is 5.0 t/ha. The plant of BINA dhan19 is about 80-90 cm tall and does not get lodged. During severe drought the plant became almost stop growing but when rain is started then it starts growing vigorously and gave almost equal yield like favorable condition. It matures within 90-105 days and thousand grain weights is about 23 g. The grain contains 7.32% protein and 23.8% amylose. Efforts are continuing towards indigenous rice cultivars of Lombur, B-11 and Hori dhan to develop new mutant variety with higher yield, improved agronomic traits and tolerant to abiotic stress.

Introduction

The continuous increase of population in the country demands more food. In turn, it requires more land for rice cultivation as rice is the staple food for 166 million people in Bangladesh and also the most important food crop in Asia and rest of the world (AIS, 2008). We are facing severe threat of climate change challenges in crop sector. In Bangladesh, rice is grown three seasons in a year i.e., Aman season (July to December), Boro season (December to May) and Aus season (March to June). Rice provides 75% of total calories and 51% of protein in our population. About 60% of the total agricultural labor force is engaged for rice production (AIS, 2008). It covers 77.96% of total cropped area in Bangladesh (AIS, 2007) and contributing 14.6% of our national GDP (BBS, 2004). It is a diploid species, with a small genome in comparison to other cultivated cereals (Moin *et al.*, 2017). The average rice yield in the country is about 2.5 t/ha. It is very low yield comparing to other rice growing countries in the world (Islam, 1989). The low yield performance of rice in the country is the effect of the cultivation of low yield potential genotypes, drought, flash-flood and soil salinity. Salinity is also one of the significant abiotic constraints to rice cultivation in the coastal areas of Bangladesh. Salt stress brings about huge losses in worldwide agricultural productivity (Moradi *et al.*, 2003; Yu *et al.*, 2016). In the world, about 400 million hectares of land are affected by high soil salinity and about 1 million hectares of land are affected by high salinity in the coastal regions in Bangladesh (Karim *et al.*, 1990). Salinity hindrances almost every aspect of the physiology and biochemistry of plants and significantly reduces yield. A number of indigenous cultivars are prone to lodging but had some degree of tolerant to salinity and submergence. Its grains are medium bold and contains 10.3% protein and 28.6% amylose (Kamruzzaman and Asaduzzaman, 2004). Mutation Breeding Project of FNCA aimed for breeding technology with major crops using irradiation either by gamma-ray or by ion-beam. Mutations are the major source of genetic variability and artificial mutations can be induced by mutagens (Wei *et al.*, 2013; Oladosu *et al.*, 2016). Many reports are available in induced mutation of rice for genetic improvements with higher yield and other agronomic traits (Azam and Uddin, 1999; Hidema *et al.*, 2003). Recently, ion beam irradiation has been appeared to utilize an effective means of inducing mutations. The biological effects of ion beams have also been investigated and observed to be shown a high relative biological effectiveness (RBE) in lethality, mutation and also to transfers high energy to the target compared to low linear energy transfer (LET) radiation such as Gamma-rays, X-rays and electrons (Blakely, 1992). It has been also demonstrated that ion beams induce mutations at high frequency and induce novel mutants in *Arabidopsis* (Hase *et al.*, 2000, Shikazono *et al.*, 2003, Tanaka *et al.*, 1997, 2002). The use of ion beams for inducing mutations in rice (*Oryza satva* L.) breeding has also been attempted (Hayashi *et al.* 2007; Hidema *et al.* 2003; Rakwal *et al.* 2008). It is generally and widely accepted that in mutation breeding induced traits become fixed during M_2 to M_4 generations (Azad *et al.*, 2010; Hamid *et al.*, 2006; Shamsuzz*aman et al.*, 1998; Azam and Uddin, 1999). Indigenous genotypes have been indicated as the tremendous sources of genes for new alleles (Evenson and Gollin, 1997; Guevarra *et al.*, 2001; Hoisington *et al.*, 1999; Jackson, 1999; Tanksley and McCouch, 1997). Based on the information mentioned above, the study was undertaken to develop new mutant variety with higher yield and yield contributing traits among the local rice genotypes in Bangladesh using carbon ion beam irradiation. In rice, mutants were developed from immature embryos (Ookawa *et al.*, 2014), calli obtained from seeds (Serrat *et al.*, 2014) and cell suspension cultures (Chen *et al.*, 2013). Seeds are, however, easier to handle and do not require a specialized structure, and is therefore, the most widely used material (Da Luz *et al.*, 2016; Oladosu *et al.*, 2016). Screening of existing landraces as well as creation of new mutant variety with improved salt tolerant traits is also a major goal for future study. In this study, we aimed to describe the possibility to get mutants with higher yield, photoperiod insensitive, and shorter plant height from local T. aman rice genotypes Ashfal and also to get mutant with higher yield and early maturity from BRRI dhan29 and it is extended to obtain mutant from NERICA10 in rice by ion beam irradiation.

Materials and Methods

Hulled rice seeds of Ashfal, BRRI dhan29 and NERICA10 were exposed to 26.7 MeV/n carbon ions with different doses of 0, 10, 20, 40, 60, 80, 100, 120,140, 160, 180 and 200 Gy at Japan Atomic Energy Agency (currently QST, Takasaki, Gunma, Japan). One hundred and fifty seeds were used for each irradiation dose. The irradiated seeds were allowed to germinate in petri-dishes. Germinated seeds were sown in seed bed to grow seedlings. Seedlings were transplanted in the field. Single seedlings were transplanted into each hill. Seedlings were transplanted at the PBGED experimental field, IFRB, AERE, Savar, Dhaka, and also at the experimental field of BINA, Mymensingh. Plot size was 5.0 x 2.0 m^2 and distance between rows and plants were maintained 20 cm and 15 cm respectively. The experiments followed RCB design with three replications. Recommended dose of fertilizers, cultural and intercultural practices were done as and when required. Porous pipe was depth into 15 cm of soil to maintain irrigation in rice field. All fertilizers were applied during final land preparation excluding urea. Urea was applied at three equal installments at 7, 30 and 55 days after transplanting. Three hand weeding were made and the plots were kept saturated with irrigation till maturity during Boro season. Heights were measured randomly from ten mutant plants of each irradiated dose at the time of harvesting. Number of days to heading was recorded as the number of days required from sowing time when 50% of plants of each line headed. Days of maturity was recorded as the number of days required from sowing time when 90% of plants of each line appeared with yellowish grains. These two data were recorded through visual observation by visiting the plots every alternate day. Number of effective tillers per plant and panicle length was measured at the time of maturity with randomly selected five competitive plants. Filled and unfilled grains/panicle was recorded from five hills per plot at harvest. Grain yield was recorded from 1 m^2 area which was later converted to yield at ton/ha at 14% moisture. Moisture data was recorded with a grain moisture meter.

Results

Table 1 showed that BINA dhan18 was cultivated at seven different zones in Bangladesh to observe the growth uniformity and yield performance. Table 2 indicated that data of yield attributing traits of mutant (RM(2)-40(C)-1-1-10) and parent (BRRI dhan29) are non-significant. Maturity period and yield was found significantly different between mutant and parent and also among the location cultivated in Bangladesh (Table 3). It was observed that highest (7.8 t/ha) yield with short (145 days) duration was observed at mutant grown at Pakkhifanda, Rangpur area over the parent. Table 3 also indicated that mutant yielded higher and required short duration to mature over parent at every location grown in Bangladesh. Table 4 proved that mutant produced long grain fine rice as grain length was recorded 9.0 (7.4) mm over parent 8.0 (6.5) mm.

Table 1. Multi location trial of BINA dhan18 at different sub-station of BINA.

Location	Date of seed sowing	Date of transplanting	Age of seedlings (days)
BINA farm, Mymensingh	02 December 2013	09 January 2014	39
Maijbari, Mymensingh	02 December 2013	10 January 2014	40
BINA sub-station farm, Magura	02 December 2013	14 January 2014	44
Farmer's Field, Magura	02 December 2013	14 January 2014	44
BINA sub-station farm, Rangpur	01 January 2014	12 February 2014	43
Pakkhifanda, Rangpur	01 January 2014	13 February 2014	44
BINA sub-station farm, Barisal	02 December 2013	31 January 2014	61

Table 2. Yield attributing traits of mutant (RM(2)-40(C)-1-1-10) over parent (BRRI dhan29).

Mutant/variety	Plant height (cm)	Effective tiller (no.)	Panicle length (cm)	Filled grains/ panicle (no.)	Unfilled grains/ panicle (no.)
RM(2)-40(C)-1-1-10	101	11.42	24.7	113	33
BRRI dhan29	100	11.87	24.5	111	33
LSD(0.05)	NS	NS	NS	NS	NS

NS- not significant

Table 3. Comparison of maturity period and yield of mutant (RM(2)-40(C)-1-1-10) with the parent variety (BRRI dhan29) at different sub-station of BINA.

Location	Maturity period (days)		Yield (t/ha)	
	RM(2)-40(C) -1-1-10	BRRI dhan29	RM(2)-40(C) -1-1-10	BRRI dhan29
BINA farm, Mymensingh	150	165	6.9	6.5
Maijbari, Mymensingh	152	165	5.8	6.3
BINA sub-station farm, Magura	157	168	7.6	5.7
Farmer's Field, Magura	155	168	5.8	5.5
BINA sub-station farm, Rangpur	155	165	7.5	7.1
Pakkhifanda, Rangpur	145	160	7.8	7.2
BINA sub-station farm, Barisal	155	170	5.1	4.9
Farmer's Field, Barisal	151	162	5.2	5.2
LSD (0.05)	-	-	0.36	
Average	153	165	6.46	6.05

Table 4. Comparison of grain characters of the mutant (RM(1)-40- (C)-1-1-10) and the parent variety (BRRI dhan29).

Mutant/variety	1000-grain weight (g)	Grain length (mm)	Grain breadth (mm)	Length: breadth ratio
RM(1)-40(C)-1-1-10	26.0	9.0 (7.4)	3.0 (2.5)	3.0 (2.96)
BRRI dhan29	20.6	8.0 (6.5)	2.5 (2.2)	3.2 (2.95)

Numbers in the parentheses indicate the values of dehusked grain.

Control (NERICA10) BINAdhan19 (Mutant)

Discussion

On the basis of lethality, ion beams induced higher frequencies of mutation than gamma rays. In view of this, seeds of Ashfal rice, BRRI dhan29 and NERICA10 were irradiated with different doses of carbon ion beams and were grown in Boro and Aman season. These results showed that photoperiod sensitivity was altered by carbon ion irradiation in case of BINA dhan14 whilst it was developed from highly photoperiod sensitive cultivar Ashfal. It was also found that plant heights of the three studied land races at M_2 progenies were significantly shortened than that of their parents. This is also observed consistent with the fact that the fertile M_2 plants had shorter plant height than their parents. This might be due to the fact that the fertile mutant lines shifted from vegetative phase to reproductive phase earlier than parents and it is caused by ion beam irradiation. It has been reported that one dominant and one recessive gene are responsible for photoperiod sensitivity in rice (Yu and Yao, 1968; Yokoo and Fujimaki, 1971; Yokoo *et al.*, 1980). It could be happened that carbon ion beams irradiation inactivated or down regulated the activity of the dominant gene in the irradiated seeds which makes the mutant lines homozygous monogenic recessive for photoperiod insensitivity. BINA dhan18 showed higher yield and early maturity compared to parent of BRRI dhan29 which could be due to the useful effect of carbon ion beam. BINA dhan19 also showed higher yield, early maturity and highly drought tolerant compared to parent of NERICA10 which also thought to the useful effect of carbon ion beam. It was obvious from the study that BINA dhan14 was developed using 200 Gy and BINA dhan18 and also BINA dhan19 was developed using 40 Gy respectively through carbon ion beam irradiation. The rest of the doses of the particular genotypes under investigation were omitted from these evaluations because they were prone to lodging for weak culm although they had shortened plants. Moreover, these progenies had shorter panicle with smaller grains and lower number of seed grains and also their inferior performance. Although the grain characteristics such as size and shape altered in case of most of the mutants but grain weight almost similar as the parent. Hence, it could be concluded that it is possible to induce fixed mutants in *indica* type rice Ashfal, BRRI dhan29 and NERICA10 through 40-200Gy doses of carbon ion beams irradiation. This result is also in agreement with the results of Honda *et al.* (2006) who reported genetically fixed mutants in M_1 generation of sweet pepper for dwarf height and yellow pericarp. Therefore, all of these suggest that heavy ion beams irradiation has unique properties that induce fixed mutation.

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