Research Paper

Selection of Culm Characteristics of Rice to Improve Lodging Resistance and Yield Components

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Abstract

Rice crop has reached its maximum potential yield due to greater photosynthetic efficiency. It is important to develop physiologically efficient plant architecture by increasing source capacity. The better option is to increase plant height up to realizable level but, lodging is a common problem in rice cultivation. Therefore, medium aged (100-109 days) rice parental lines and available accessions (78) were evaluated in 2020/21 *Maha* season at the Rice Research and Development Institute, Batalagoda (i) to determine variability of culm characters of selected varieties, (ii) to determine appropriate characteristics with high heritability and genotypic relation on lodging, yield and yield component, (iii) to explore maximum realizable culm length, diameter and strength that could be utilized to achieve lodging resistance, (iv) to find out suitable donor parents for future rice breeding programmes. Culm characters, lodging, yield of accessions and yield components were recorded. Length, width, thickness, diameter and lignified cells of culm are highly heritable characters. Alteration of culm length up to 90 cm with 2.8 N culm strength and increasing culm diameter up to 10.0 mm could hold greater source capacity for large panicle bearing varieties. Bg Acc 89 *Sudu Heenati,* NSICRC 182, Bg Acc 627 *Dahanala*, and Bg Acc 611 *Batapolal* are suitable traditional donor parents for greater culm characteristics.

Keywords: Culm characteristics, Donor parents, Heritability, Improvement, Lodging resistant, Rice varieties

Introduction

High yielding rice varieties have been introduced to the farmers aiming at fulfilling the world's consumer demand for rice (Jian *et al*., 2011). The present research finding shows that, rice crop has reached its maximum yield and greater photosynthetic efficiency (Hettiaratchi *et al*., 2011). However, plant breeders put their maximum efforts to improve rice yield with the expectation of fulfilling future national requirement for paddy. The most promising biological characters of rice, considered by plant breeders at present, are increasing productivity through increased assimilate partitioning, resistance/ tolerance to abiotic and biotic stresses and developing improved resistance to lodging (Kashiwagi *et al*., 2008). Nomura *et al*. (2019) developed a high yielding lodging resistant variety, which is free of semi dwarf gene (sd_1). Lodging is one of the main reasons for yield loss in rice cultivation (Kajala *et al*., 2011). Lodging resistance is a complicated quantitative trait that is influenced by variety of factors, including culm characteristics such as morphology, culm diameter and length, cellulose content (Chen *et al*., 2014) and some environmental factors. Moreover, culm mechanical strength has been identified as an important agronomic trait in crop breeding (Li *et al*., 2009). Plant improvement requires a greater variation in traits. Increase of potential yield by physiological changes (Peng *et al.*, 2008) is a timely essential activity. The present study was conducted with the expectation of finding possibilities to improve lodging resistance in rice and to increase rice productivity thereby. Therefore, medium aged parental lines and available accessions were evaluated, to determine variability of physiological and morphological culm characters of parental lines and traditional accessions. To select appropriate characteristics having high heritability related to lodging resistance, yield and yield component and to find out suitable donor parents for future breeding programmes.

Materials and Methods

A field experiment was conducted at the research field of the Rice Research and Development Institute (RRDI), Batalagoda to screen 13 medium aged (100- 109 days) parental lines, 44 medium aged accessions selected from Gene bank of RRDI, one accession from Plant Genetic Resource Center (PGRC) and 19 recommended medium aged varieties and promising lines of rice, which were selected as parental lines with high yielding and lodging resistant from National Co-ordinate Rice Varietal Trials. Those 78 accessions (Table 1) were arranged in a Randomize Complete Block Design with 2 replications during 20/21 *Maha*.

Impact of culm characteristics on lodging and yield related traits were investigated. Eighteen days old single seedlings were transplanted at 20 cm (within rows) × 15 cm (between plant) spacing.

Table 1. List of tested accessions, varieties, parental lines and promising lines and traditional varieties

Accession number	variety	Type of variety/accession	Accession number	variety	Type of variety/accession
15	SACDTSAC-DT-101	Rice germplasm collection	615	Bg-34-8	Rice germplasm collection
16	SACDT-105	Rice germplasm collection	619	Bg-33-2	Rice germplasm collection
213	Basmathie	Rice germplasm collection	620	Bg-33-2	Rice germplasm collection
280	Herath Banda	Rice germplasm collection / traditional	621	Bg 94-1	Recommended variety
445	Pokkali	Rice germplasm collection / traditional	622	Bg 94-2	Rice germplasm collection
473	Seeraga samba	Rice germplasm collection / traditional	625	Cheenadi	Rice germplasm collection
489	Sudu Heenati H.F.9	Rice germplasm collection / traditional	627	Dahanata	Rice germplasm collection
530	62-355	Rice germplasm collection	629	Dahanala 2220	Rice germplasm collection
555	BgSudubalawee	Rice germplasm collection / traditional	637	Gonabaru	Rice germplasm collection
573	Sudu wee	Rice germplasm collection / traditional	641	H-7	Rice germplasm collection
601	Ai-Nan-Sao	Rice germplasm collection	642	H-10	Rice germplasm collection
602	Balakara	Rice germplasm collection / traditional	644	Haleliya	Rice germplasm collection
603	Balakara	Rice germplasm collection / traditional	652	Handiran	Rice germplasm collection
605	Balakaharamana	Rice germplasm collection / traditional	654	Handiran	Rice germplasm collection
607	Batapolael	Rice germplasm collection / traditional	656	Handiran	Rice germplasm collection
608	Batapolael	Rice germplasm collection / traditional	664	Heenati	Rice germplasm collection
609	Batapolael	Rice germplasm collection / traditional	665	Heenati	Rice germplasm collection
611	Batapolael	Rice germplasm collection / traditional	667	Heenati	Rice germplasm collection
612	Batapolael	Rice germplasm collection / traditional	672	Heenkarael	Rice germplasm collection
613	Batapolael	Rice germplasm collection / traditional	677	Heraswee	Rice germplasm collection
614	Bg-34-8	Rice germplasm collection	678	Herath	Rice germplasm collection
	IR 71033-121-15	Rice germplasm collection		IR 11749-B-B-CMU-6-1-B	Rice germplasm collection
	Purple seed	Rice germplasm collection		OB 2569	Rice germplasm collection
	IR 64	Rice germplasm collection		HHZ 35	Rice germplasm collection
	NPB 2B93-1-11	Parental line		SN 382	Rice germplasm collection
	HHZ 28	Parental line		SVIN 115	Rice germplasm collection
	NSICRC 182	Parental line		SVIN 066	Rice germplasm collection
	IR 117 841-8-1-RGA-1	Parental line		At 10-1350	Promising line
	Bg 11-802	Promising line		Bg MA 2	Promising line
	Bg 16-598	Promising line		At 373	Recommended variety
	Bg 354	Recommended variety		Bg 374	Recommended variety

Table 1. List of tested accessions, varieties, parental lines and promising lines and traditional varieties continued

Accession number	variety	Type of variety/accession	Accession number	variety	Type of variety/accession
	At 354	Recommended variety		Bg 10-1407	Promising line
	Bg 358	Recommended variety		17 R	Promising line
	Bg 360	Recommended variety		HT 7	Parental line
	At 362	Recommended variety		Bg 359	Recommended variety
	Bg 366	Recommended variety			
	Bw 367	Recommended variety			
	Bg 369	Recommended variety			
	Suwadel	Traditional variety			

Each variety consisted of 3 rows, which were in 3 m lengths. Data were collected from the 3rd, 4th and 5th hill of middle row at flowering stage on culm length (CL) (Wu *et al*., 2011), culm diameter (CD), culm thickness (CT), number of Paranchyma cells (PC), collenchyma cells (CC) and lignified cells (LC) along the radius in transverse section of the culm using Euromex microscope (Model: OX. 3045, Holland). Culm strength (CS) was measured using locally made equipment (Figure 1), which was consisting of an adjustable wooden frame. Culm placed on top of the frame and a weight was hanged at the centre of the culm.

The first weight, which broke the culm, when the hanging weight was increased, was taken as the culm strength (kg) and converted to Newton (N). At physiological maturity lodging severity was recorded in a scale from 1 to 9 where 1= no lodging and 9 = 100% lodging (Rani *et al*., 2017). Further, five main panicles from the middle row were harvested from each variety and number of grains per panicle (GP), 1,000 grain weight (TGW) and percentage of filled grain (FG %) were calculated. Culm length (CL), number of panicles per hill (PH) and grain yield (YLD) of plants were recorded. Data were subjected to the Analysis of Variance (ANOVA) using SAS 9.1 statistical software and least significant differences for all parameters were recorded. Using error mean square of each trait and mean square of varieties, genetic variance (GV), environment variance (EV), phenotypic variance (VP), and heritability (h2), were calculated (Table 2) (Johnson *et al*., 1955).

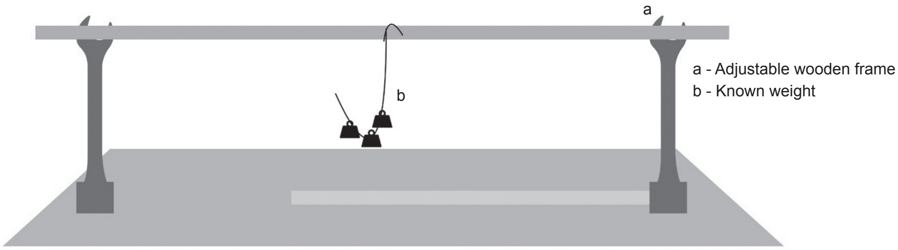

Figure 1. Layout of equipment made for measure culm strength

According to Burton. (1952) phenotypic and genotypic coefficient of variations (PCV and GCV %) were calculated (Table 2).

Averages of each character of 78 varieties were used to form cluster analysis (Eluclidean distance and Ward linkage) and Factor analysis was done by Minitab 14 version. Cluster analysis built hierarchy of clusters and detects the variance of characters based on the length and radius of the by plots. Then, culm characteristics were subjected on stepwise regression analysis to find the relationship on yield of tested characters. Using following equation *yield = 1.38+0.207CD-0.025CS-0.014CL*

where CD = culm diameter, CS = culm strength, CL = culm length

Results and Discussion

Diversity and heritability of characters

Varieties, which recorded maximum and minimum values for each trait, and diversity of characters, are shown in the Table 3. Greater variations recorded among the varieties for culm characters, yield and yield components. However, variety selections based on the yield components are much more reliable (Gatti *et al*., 2005). Further, yield improvement needs possible physiological modifications. Finding the genetic influences of novel physiological characteristics for future breeding programs are important.

Table 2. Equations for calculating phenotypic variance, heritability, coefficient of variation for genotype and phenotype

Equation			Reference
Genetic variance (VG)	=	(Genotype Ms – Error Ms)/number of replicates	Karim *et al.* 2007
Environmantal variance (VE)	=	Error Ms	Johnson *et al.* 1955
Phenotypic Varience (VP)	=	VG + VE	
Broad – sense heritability (h^2)	=	VG/VP × 100	
Phenotypic coefficient of variation (PCV 5)	=	Phenotypic standard deviation/population mean	Burton, 1952
Genotypic coefficient of variation (GCV%)	=	Genotypic standard deviation/population mean	

Table 3. Mean, maximum, minimum, and least significant difference of culm characteristics, lodging severity, yield of accessions, yield components and name of accessions obtained maximum and minimum values except lodging

Character	Mean	Maximum	Minimum	Accession maximum recorded	Accession minimum recorded	LSD	CV %
Parenchyma cells [1]	5.76	11.3	3.5	BgAcc Sudubalawee	BgAcc 679 Herath	1.6	19.8
Collenchyma cells [1]	4.7	8.2	2.7	BgAcc 611 Batapolal	IR71033-121-15	1.4	25.2
Lignified cells [1]	2.4	11	1	BgAcc 555 Sudubalawee	meny accessions	2.3	36.2
culm thickness (mm)	0.95	1.4	0.5	Bg 11-802	Bg359, HT7	0	3.7
Culm diameter (mm)	4.6	6.4	3.1	NSICRC 182	At 354	0.1	2.9
Culm Strength (N)	2.4	3.5	1.4	Bg 11-802, BgAcc 627 Dahanala	At 354, IR71033-121-15, IR64	0.0	1.3
Culm Length (cm)	88.6	131.7	58	BgAcc 455 Pokkali	Purple seed	4.5	4.4
Grains per panicle	157.3	310.8	74	Bw 367	HHZ 28	19.1	10.7
1,000 grain weight (g)	24.9	30.2	11.7	IR11749-BB-CMU-6-1-B	At373	1.7	6.1
Number of panicles per hill	10.7	16.8	5.8	H7	BgAcc 612 Batapolal	1.8	15
Filled grain %	64.1	77.9	38.7	BgAcc 607 Bataploal	BgAcc656 Handiran	2.3	3.1
Yield of accessions (kg of 2.97 m^{-2})	1.05	2	0.3	Bg 358	BgAcc 679 Herath, BgAcc 672 Heenkaraal	0.3	26
Lodging severity	4	9	1			0.5	11.3

Note : [1] – Average number of cells along the radius in transverse section of the culm

Heritability, which controls the particular character and the character's phenotypic consistency, is significant for breeding success (Ullah *et al*., 2012; Ene *et al*., 2016). Genotypic variance, environment variance and phenotypic variance, heritability, genotypic and phenotypic correlation coefficient of culm characteristics and the yield related traits of 78 varieties were explained in the Table 3. Genotypic correlation coefficient of culm characteristics, yield related traits were greater than phenotypic correlation coefficient. Environmental influence is lesser than genetic factors of those traits.

The highest Genotypic Coefficient of Variance (GCV%) was recorded for lodging severity (91.1%) and Phenotypic Coefficient of Variance (PCV) was 80.9. Number of lignified cells along the radius of the cross section of the culm was recorded 79.6 % of GCV % and 67.1 of PCV %. Genetic impact on lodging and lignified cells are greater and it is required to investigate environmental influences on lignified cells, its correlation, on lodging. Broad sense heritability (h^2) of lignified cells, culm thickness, culm diameter, culm strength, and culm length recorded 73.1, 97.8, 97.3, 99.6 and 96.2%, respectively (Table 4). Yield and yield component of rice have greater genotypic effect, thereby genetic expression is maximum (Sing *et al*., 2018). Table 4 further explained that, panicles per hill, grains per panicle, filled grain % and 1,000 grain weight as well as yield of tested 78 accessions had greater genotypic correlation coefficient (GCV %) and a broad sense heritability. Thus, it was suggested that, yield and yield component recorded greater genetic expression.

Results of principle component analysis

Culm characteristics and yield related traits were loaded by 5 principal components, which were greater than 1 eigen values. They were representing the 70.6% of variability; loading plot explained the strength of variation of traits by length of the line and cosine of the angle (Figure 2).

Lodging negatively correlated with yield by greater variance (cosine value of yield was approximately 180°). Grains per panicle (GP), culm diameter (CD), and culm strength (CS) have negatively correlated with lodging but strength of the variation has decreased in GP, CD and CS consecutively. Number of panicle (NP) and filled grain % have negatively correlated, and their strength of correlation was moderate. Lodging positively correlated with culm length (CL) and 1,000 grain weight, the strength of variation was greater in culm length. Type of the cells in culm did not show any correlation with lodging. Culm thickness (CT) did not show clear correlation and strength of variation on lodging. Similar results were reported by Wu *et al*. (2011). Among the tested culm characteristics, a culm length, diameter and thickness could be used as selection criteria on lodging resistance. Varieties having thicker culms with higher number of vascular bundles in culm and leaves would result comparatively higher yield (Wu *et al*., 2011).

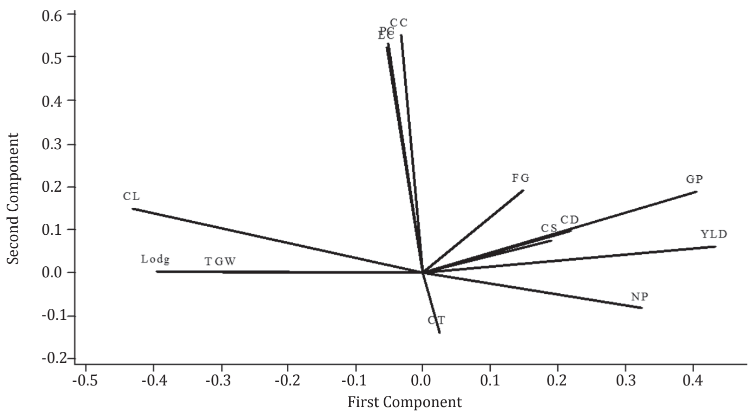

Figure 2. Strength of variation in traits between 1st and 2nd components.

Table 4. Mean squares, genetic variance (Vg), environmental variance (Ve) and phenotypic variance (Vp) along heritability (H^2) for culm characteristics and yield related traits of 78 rice varieties and phenotypic and genotypic correlation coefficient (PCV % and GCV %)

Character	Error Ms	Variety Ms	Genetic variance (Vg)	Environment variance (Ve)	phenotypic variance (Vp)	Heritability % (h^2)	Phenotypic correlation coefficient (PCV %)	Genotypic correlation coefficient (GCV %)
Parenchyma cells [1]	1.280	2.0	0.4	1.3	1.6	21.95	19.9	24.9
Collenchyma cells [1]	1.410	2.5	0.5	1.4	2.0	27.88	23.9	32.0
Lignified cells [1]	0.700	4.5	1.9	0.7	2.6	73.08	67.1	79.6
Culm thickness (mm)	0.001	0.1	0.0	0.0	0.0	97.80	23.0	23.8
Culm diameter (mm)	0.010	0.7	0.4	0.0	0.4	97.33	13.4	13.7
Culm Strength (N)	0.001	0.5	0.3	0.0	0.3	99.63	22.1	22.4
Culm Length (cm)	15.600	809.2	396.8	15.6	412.4	96.22	22.7	23.8
Grains per panicle	284.800	6105.1	2910.2	284.8	3195.0	91.09	35.1	39.3
1000 grain weight (g)	2.300	32.0	14.9	2.3	17.2	86.59	16.1	17.1
Number of panicles per hill	2.630	12.4	4.9	2.6	7.5	65.00	23.2	27.3
Filled grain %	3.900	95.4	45.8	3.9	49.7	92.15	10.8	11.1
Yield of accessions (kg of 2.97 m^{-2})	0.070	0.4	0.2	0.1	0.2	70.21	42.9	57.2
Lodging severity	0.200	20.9	10.4	0.2	10.6	98.10	80.9	91.1

Note: [1] *– Average number of cells along the radius in transverse section of the culm, Ms –Mean square*

Table 5 explained that, culm length and lignified cells negatively influenced on grains per panicle with a contribution of 17.5% and 2.1% consecutively. Culm diameter (14.9 %), collenchyma cells (6.2%) and parenchyma cells (1.8%) showed a positive impact on grains per panicle. Lignified cells are highly heritable but did not correlate with lodging. Culm strength showed a negative impact by 3.5% and culm length positively impact by 12.9% on seed weight. Varieties which are having heavy grains with longer culm will be more prone to logging. According to Figure 2, weight of seeds (TGW), lodging and culm length strongly correlated and their variations were very strong. Therefore, rice varieties having heavy panicles have to be improved by adjusting their culm length and strength, which could be achieved with the contribution from most of the traditional accessions. Culm length had strong and negative impact of 30.2% on number of panicles and 37.7% on yield of accessions (Figure 2 & Table 5). Meanwhile, culm diameter and number of parenchyma cells showed a positive impact on grain yield by 7.3 and 3.0%, respectively. Above results suggested that Parenchyma cells are highly correlated with strong variation on culm length among the tested accessions. Culm length, its diameter and strength could be measured with simple means on the yield improvement and lodging resistance. Plant height is not an important factor in determining the lodging resistance (Ookawa *et al*., 2010), but decreasing the culm length is essential to improve lodging resistance in rice (Chuanren *et al*., 2004). Most of the traditional varieties are taller varieties and they are highly vulnerable for lodging.

Therefore, it is important to select appropriate culm length, which has ability to bear a large panicle and leaves without breaking the strength of culm. Greater source capacity is the most critical factor, which delivers assimilate for the large panicle when creating a superior variety.

Table 5. Impact of culm characteristics and lodging on yield

Dependent variable	Character	PE	Partial r^2	F value	Pr>f
Grains per panicle	CL	-1.27	0.175	16.0800	0.0001
	CD	29.92	0.149	16.5800	0.0001
	CC	14.75	0.062	7.5200	0.0076
	CL	-7.46	0.021	2.6400	0.1086
	PC	7.21	0.018	2.2000	0.1423
1,000 grains weight	CL	0.07	0.129	11.2600	0.0012
	CS	-1.44	0.035	3.1600	0.0794
Panicles per hill	CL	-0.07	0.302	32.8500	<0.0001
yield of accessions	CL	-0.01	0.377	45.9900	<0 .0001
	CD	0.19	0.073	9.9100	0.0024
	PC	0.06	0.030	4.2400	0.0430

Note: PE - parameter estimate, CL- culm length, CD - culm diameter, CS - culm strength CC - collenchyma cells PC - parenchyma cells

New improved varieties have photo synthetically efficient leaves. Therefore, increase of plant height might provide additive effects in improving yield. Achieving stronger culms with appropriate diameter and high amount of collenchyma cells are very essential in developing superior varieties.

Results of cluster analysis

Hierarchical clustering is an algorithm that builds hierarchy of clusters, where the algorithm starts with all the data points assigned to a cluster of their own. Five clusters were loaded 79.9% of the similarities in Ward linkage and Euclidean Distance. Table 6 explains the averages of the tested traits of each cluster.

Table 6. Cluster averages of tested variables

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
CL	71.01	77.13	80.36	105.45	107.97
CT	0.93	0.92	0.95	0.98	0.97
CD	4.40	5.26	4.54	4.31	4.60
CS	2.16	2.81	2.36	2.39	2.33
PC	5.77	6.14	5.42	5.19	6.08
CC	4.54	5.58	4.36	4.27	5.21
LC	2.65	2.57	1.90	2.24	2.71
GP	129.69	274.53	186.42	95.61	132.41
TGW	25.42	20.20	24.01	26.79	26.34
NP	12.98	11.86	10.96	9.06	9.31
FG	64.03	66.39	64.96	58.98	65.96
Lodging	2.25	1.44	3.27	5.46	6.67
YLD	1.16	1.41	1.29	0.64	0.78

Note: CL – culm length, CT – culm thickness, CD – culm diameter, CS – culm strength, PC – parenchyma cells, CC- collenchymas cells, LC – lignified cells, GP – grains per panicle, TGW- 1,000 grain weight, NP – number of panicles, FG- filled grain %, YLD – yield of accessions.

Cluster 2 recorded the highest accession yield (1.41 Kg of 2.97 m^{-2}) and no lodging and greater grains per panicle (Table 5). This cluster recorded 77.1 cm culm length, 5.3 mm of culm diameter and 2.8 N of culm strength. Variety Bg 358, Bw 367, At 373, Bg 374, Bg 375 (Bg 10-1407), Bg 11-802, Bg 17R and Purple seed were grouped in cluster 2 (dendogram is not shown). All of them are new improved recommended varieties except Purple seed. Variety Bg 358 produces higher yield but under favourable direct sowing condition this variety experiences lodging. Thus, it is essential to increase culm diameter and strength. Varieties Bg Acc 489 *Suduheenati,* NSICRC 182, Bg Acc 627 *Dahanala*, and Bg Acc 611 *Batapolal* could be used as donor parents for improving CL, CD, CS and LS, respectively. Correlation analysis of culm length on yield of recommended varieties recorded the positive correlation (r = 0.43, P = 0.08) and increasing trend. Thus, it is needed to strengthen the culm by increasing culm diameter using donor parents. Correlation analysis explained the relationship between culm length, culm diameter and culm strength (r^2 = 42.8% and model was significant at P = 0.0001).

Equation explained that increasing culm length up to 90 cm with 2.8 N culm strength and increased culm diameter up to 10.0 mm have increased the accession yield up to 2.19 kg. Wu *et al*. (2011) obtained 11.2 t ha^{-1} greater yields from 9.22 mm large culm variety compared to 8.26 to 9.47 mm small culm varieties, which are having 7.58 to 9.47 t ha^{-1} grain yield.

Conclusions

Culm length, diameter and strength are better selection criterion for lodging resistant and yield of rice varieties. Bg 358, Bw 367, At 373, Bg 374, Bg 375, Bg 11-802, Bg 17R and Purple seed are cluster together with greater yield, culm diameter, culm strength and spikelet per panicle. Thus, above varieties are most suitable for further modifications. Increasing culm length up to 90 cm with 2.8 N culm strength and increasing culm diameter up to 10.0 mm could hold a greater source capacity for large panicle varieties and attain yield up to 2.19 Kg of 2.97 m^2 area by increasing filled grain percentage. Locally available donor parents are Bg Acc 489 *Suduheenati*, NSICRC 182, Bg Acc 627 *Dahanala*, and Bg Acc 611 *Batapolal*.

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