

Developing Sugarcane Varieties Suitable for Mechanized Production Strategies and Prospects

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Abstract: Sugarcane is a labour-intensive crop. Given the current trend in workforce availability for sugarcane production, it has been observed that contemporary machinery use is unavoidable. The present study was taken up with objective to develop erect and non-lodging sugarcane plant types suitable for mechanical harvesting and to test the suitability of developed sugarcane clones for mechanical harvesting. Fifteen clones evolved from fluff supply programme were analyzed for genetic parameters which are amicable for mechanical harvesting. Results depicted that there were remarkable differences between genotypes. Analysis of variance revealed that there is a significant difference between the genotypes under study. High GCV and PCV values were depicted by Tiller population 120@DAP (000s/h), NMC, HR Brix %, Lodging resistance index, average ratooning ability and leaf angle inclination respectively. Regression analysis showed that harvesting efficiency was positively influenced by basal/middle stem ratio (+6.03), cane yield (+0.79) followed by number of millable canes (+0.50) respectively. The model explains 99.95% of the variance in harvestability. Higher Basal/Middle diameter ratio and more lodging resistance index (>2.31) improve harvestability. P values are < 0.05 for all the predictor variables indicating the significance of each variable. Harvesting efficiency mainly depends on lodging resistance index, ratio of basal to middle stem diameter, number of millable canes, optimum height, less crown weight to cane weight ratio, maximum tillering at 120 days after planting, high cane yield, low harvesting time/acre and leaf angle inclination are some of the traits where a breeder has to concentrate for the development of genotypes that are suitable for mechanical harvesting. From the study it was revealed that the new sugarcane varieties viz., 2016A642, 2016A381, 2016A385 and 2016A379 were highly suitable for mechanical harvesting in view of their mechanical amicable traits

Keywords: Mechanical harvesting, harvesting efficiency, principal traits, Variance analysis and correlation analysis.

INTRODUCTION

The sugarcane cultivation area has decreased to 40,000 hectares after years of decline. Despite the fact that sugarcane yields higher returns than paddy, producers are transitioning from sugarcane cultivation to other crops. The high input costs and labour shortages in Andhra Pradesh resulted in the reduction of 29 sugar mills (10 cooperative and 19 private) to 5 (1 cooperative and 4 factories) (www.indiatimes.com). Timely and cheap sugarcane harvesting

is becoming a concern, especially in tropical regions. Managing a large fleet of laborers' to supply the mill with cane is difficult. Delays in harvesting affect sugarcane quality, productivity, juice quality, and sugar recovery. Under these conditions, the sugar industry is seeking automated ways to harvest sugarcane at a fair wage. Mechanical harvesting allows green cane harvesting, reducing greenhouse gas emissions from pre-harvest burning.

Because mechanizing the sugarcane crop culture would solve the problems of a lack of workers, high costs of cultivation, hard work, and getting cultural operations done on time, it is necessary to develop mechanization-friendly varieties to increase the productivity of cane per unit of time, area, and energy. Also, finding the best clones that can be mechanically harvested is important to make production more efficient, lower costs, enhance cane loading efficiency, and reduce losses in the field. This will also encourage sugarcane farmers to grow more cane (Braun beck et al,1999). Mechanization throughout the production process is not only a fundamental solution to the lack of labour but also an important method for modernizing the technologies used in agricultural production, breaking through yield limitations, and reducing energy consumption. According to the requirements of production at different stages of development, the mechanization of sugarcane production can be reached at various levels to reduce labour intensity, minimize labour costs, improve work efficiency, and achieve overall economic benefits. In India, mechanization throughout the sugarcane production process is still in its early development stages due to limitations in land resources, technology, equipment, organization, and management, this process has not yet brought about the economic benefits that a mechanized system should provide and has not reached an ideal yield through the integration of Agricultural machinery and agronomic practice (Zhang et al,2021 & Liu et al 2023)

REQUIREMENTS FOR SUGARCANE GENOTYPES IN MECHANIZED PRODUCTION

In sugarcane fields, the efficient and cost-effective utilization of machinery relies on matching crop varieties and agronomic practices (Wei & Bei, 2021). Existing Indian sugarcane clones were mostly selected from

hybrid combinations several years or even over a two three decades ago. During the breeding programmes, the traits required for mechanical operations have not yet been considered. As a result, in recent years, mechanical harvesting trials and demonstrations have shown that the sugarcane clones are generally incompatible with mechanical operations (Que et al 2014)

The sugarcane clone is required to have the desired growth characteristics, such as quick and even germination, emergence, and tillering, a high rate of stalk population from tillers, uniform growth rate of the plants, and minimal sprouting in autumn and winter. After planting, robust seedlings with uniform growth can grow as quickly as possible, forming a seedling population with vigorous and even growth, which facilitates inter-row cultivation and helps to improve work efficiency and minimize damage to sugarcane seedlings during mechanical operation (Mahadevaiah et al,2021;Meena et al 2022; wang et al 2023 and Li et al,2016)

It is important that the plants exhibit an upright growth habit, with erect leaves that are easy to detach. The variety should also be resistant to wind and lodging. Plants with few or no aerial roots are mostly desirable. Varieties that are upright and resistant to lodging may help in reduce the rate of stem breakage during mechanical harvesting, ensuring the quality of the harvest (Li et al,2017; Li 2019 and Gao et al 2019).

Selecting varieties with strong ratooning ability is an important procedure that affects the overall effect of mechanical operations in sugarcane fields. Sugarcane varieties with strong ratooning ability exhibit several excellent characteristics, such as strong, rapid, and even tillering, which facilitate earlier row closure under a wider row spacing (Xu et al (2021; Islam et al,2023;Wu et al;2023 and Shang;2016)

Sugarcane varieties suitable for mechanization should possess not only high

yield, high sugar content, and resistance to stressors that include diseases, pests, drought, cold, wind, salt, and poor soil, but also strong ratooning ability, bulging stubbles, and deep-set bud eyes. These traits are beneficial for protecting sugarcane buds from mechanical damage. Additionally, sugarcane varieties with moderately high fiber content in the stem, the ability to stand upright and resist lodging, easy leaf detachment, loose and thin leaf sheaths, dense cane tissue, and strong sucrose retention and conversion capabilities are suitable for mechanical harvesting (Xia et al 2017; Yue, 2021; Ali Javed 2015; and Reddy et al 2023)

An essential part of India's sugarcane production system is the cultivation of two or three successive cane crops from a single planting; this makes sugarcane a unique agricultural crop in terms of its adaptability to a wide range of agro climatic conditions. (Xia et al, 2017) Under these conditions, the sugar industry is seeking automated ways to harvest sugarcane at a fair wage. In view of the facts that mechanization of sugarcane crop culture would solve the ever increasing problems of scarcity of labour, cost of cultivation, drudgery and timely completion of cultural operations, development of mechanization amicable varieties is inevitable for improving the cane productivity per unit time, area and energy. Furthermore, identification of superior clones suitable for mechanical harvesting is essential so as to improve the production efficiency, cost effectiveness, cane loading efficiency infield losses and also encourage the sugarcane growers towards cane cultivation. (Yue, 2021). Analysis of variance and regression analysis of mechanical harvesting amicable traits will assist in isolating promising high yielding lines suitable for mechanical harvester. The present study was taken up with objective to develop erect and non-lodging, high leaf angle inclination, less crown weight sugarcane plant types suitable for mechanical harvesting and

to test the suitability of developed sugarcane clones for mechanized harvesting.

MATERIALS AND METHODS

21 genotypes of sugarcane along with two checks, 87A298 and 83V15 were taken for the study of mechanical harvesting amicable traits (Table-1). The experiment was conducted at regional agricultural research station Anakapalle. Randomized block design with 3 replications and Four rows makes up the 1.2 m x 6 m area. Planting was done at 12 buds per metre row. A decent crop was achieved by following all cultural practices. Data were collected in accordance with conventional statistical methods for yield, quality attributes, and mechanization amicable parameters, specifically such as Tiller population after 120 days after planting, number of millable canes (000/ha), cane yield, cane diameter, HR Brix%, cane length, ratio of basal to middle stem diameter, lodging resistance index, single cane weight, average ratooning ability, crown weight/single cane weight, harvesting time (hours/acre) and harvesting efficiency.

At 90-120 days maximum tiller production occurs in Sugarcane. Number of tillers at 120 days after planting was recorded in each plot for each genotype, number of millable canes was counted. The quantity of millable canes was enumerated in each plot. A measuring tape was employed to ascertain the length of a sample of ten canes. A vernier calipers was employed to measure the diameter of the same ten canes, with the measurement region designated as one third of the cane's height (from the base to the apex). The ten canes were subsequently weighed, and the average weight was calculated. Cane productivity was determined by the weight of all millable canes per plot divided by the area of each plot (t/ha). Resistance grade was determined using (Ali Javed, 2015) partition approach with modifications. The lodging angle between the stem's top and base and the ground's

TABLE 1: Erect, Non lodging, Self Stripping, Less Crown Weight, leaf angle inclination Genotypes developed through fluff supply programme					
Clonal Stages (I, II and III) Clones in Final Evaluation Stage					
S.no	Parentage	Clones	Sno	Parentage	Genotype
1	ISH 100XCo87268	2016A 349	1	ISH 100XCo87268	2016A 379
	(16/39)	2016A354	2	ISH 100XCo87268	2016A 380
		2016A 355	3	ISH 100XCo87268	2016A 381
		2016A358	4	ISH 100XCo87268	2016A 382
		2016A 360	5	ISH 100XCo87268	2016A 385
		2016A 361	6	CoA93082XCo89029	2016A395
		2016A 369	7	Co86032XCoT8201	2016A 642
		2016A 370	8	Co86032XCoT8201	2016A 643
		2016A 377	9	Co86032XCoT8201	2016A 644
		2016A 378	10	Co86032XCo94008	2016A 644
		2016A 379	11	Co86032XCo94008	2016A 645
		2016A 380	12	Co86032XCo94008	2016A680
		2016A 381	13	Co86032XCo94008	2016A674
		2016A 382	14	Co86032XCo94008	2016A 684
		2016A 383	15	Co86032XCo94008	2016A 685
		2016A 385		Standards	87A298
2	CoA93082XCo89029	2016A395			83V15
	(2/3)	2016A 396			
3	Co86032XCoT8201	2016A 641			
	(3/3)	2016A 642			
		2016A 643			
4	Co86032XCo94008	2016A 644			
	(7/40)	2016A 645			
		2016A680			
		2016A674			
		2016A 684			
		2016A 685			
		2016A 686			
5	ISH100PC	2016A 757			
	(2/6)	2016A 759			
Standards in Clonal Stages					
	1	87A298			
	2	83V15			
	3	Co6907			
	4	Co7219			

perpendicular line determined categorization (Table 2).

Table 2: Lodging Resistance Index of Sugarcane Clones

Grade for Lodging	Angle obtained	Lodging Resistance
Grade 1(1-1.6)	>60°	Highly lodging
Grade 2 (1.61-2.30)	30-60°	Moderately Lodging
Grade 3(2.31-3.00)	0-30°	Erect

Computation of lodging resistance index (LRI) using the equation (Hao et al, 2008)

$$LRI = \sum (g_i \times n_i) / N \times 100\%$$

Where N is the total number of stalks investigated, g is the lodging grade, and n is the number of lodging stalks in a lodging grade. Classification was made according to grades such as Grade 1 (1-1.6, high lodging), Grade 2 (1.61-2.3, moderate lodging), Grade 3 (2.31-3, erect) respectively. The middle sections of the basal and middle stem internodes were

measured with a vernier calipers during the mature stage. At the mature stage, cane liquid was extracted and measured using an ATAGO handheld saccharometer to measure HR Brix%. Average ratooning ability = $(\Sigma R_n) / n_r$, the total of the yields of n ratoon crops is ΣR_n , where n_r is the number of ratoon crops. The ratio of crown weight to cane weight is determined by utilising the top crown weight and the cane weight. Crown weight refers to the mass of the residual crown segments of canes following crop harvesting. Harvesting time is measured by means of stop watch right from beginning to end of harvest of crop for one acre. Harvesting efficiency was measured through percent of successful harvest of millable canes and low harvesting time required taking 9 hours as average time for harvesting one acre of crop. Data were statistically analyzed (Panse and Sukhatme; 1967). ANOVA was done using Randomized Block Design for each character (Dewey and Lu, 1959). Regression analysis was done to draw the equation of regression taking harvesting efficiency as dependent variable and other variables as predictors. Minitab and Excel software were utilized for drawing the results.

RESULTS AND DISCUSSION

Analysis of variance revealed that there is a significant difference between the genotypes under study. (Table 3) Low, medium, and high PCV and GCV values are 0 to 10%, 10 to 20%, and >20% (27). The calculated phenotypic coefficient of variation (PCV) was larger than genotypic coefficient of variation (GCV) for characteristics, indicating greater environmental influence on total variance. Low GCV and PCV values were put forth by Crown weight/Single cane weight (7.93, 9.22), harvest time hours/acre (8.22, 10.82) and harvest efficiency (%). (9.43, 11.42) respectively. Moderate values were depicted by cane yield (t/ha) (13.8, 16.72), Cane length (m) (14.52, 15.33), Cane diameter (cm), (12.56, 12.90) and ratio of

basal to middle stem diameter (14.84, 16.22). High GCV and PCV values were depicted by Tiller population 120@DAP (000s/h) (26.81, 29.51), NMC (000s/h) 21.04, 23.24), HR Brix % (20.42, 24.51), Lodging resistance index (20.87, 23.24) and Average Ratooning ability (t/ha) (24.58, 27.84). Using genetic coefficient of variation alone to assess heritable variation may be misleading. Genotypic coefficient of variation is not a reliable measure of heritable variation and should be addressed with heritability. Low (0–30%), moderate (30–60%), and high (60%+) heritability levels exist. This study did not find low or medium heritability. All characters were highly heritable. (Siva Subramanian and Menon, 1973). Selection breeding for variety enhancement based on these qualities may be reliable. However, heritability does not indicate how much genetic improvement genotype selection would produce. Thus, heredity and genetic progress should be considered. GA: Genetic advance Genetic advance is the genotypic value enhancement of new population traits over the base population. Genetic advance as a percentage mean is low (0–10), moderate (10–20), and high (>20). The genetic advance as a percentage of mean was high for cane diameter (34.82), HR Brix% (34.52), Single cane weight (33.84) and Lodging resistance index (32.21). Thus, additive genetic factors govern these traits, confirming that selection based on phenotypic performance is preferable for variety improvement (Table 4)

CORRELATION MATRIX AND REGRESSION LINE

Fig. 1 shows correlation matrix with harvestability (28). Highest correlation was shown by cane yield (1) followed by number of tillers at 120 days after planting (0.93), number of millable canes (0.93), HR brix% (0.84), Basal to middle stem ratio (0.83) and lodging resistance index (0.8) respectively. Lowest value was depicted by cane length (0.074) and

cane diameter (0.17). It gives an idea that cane should be erect more NMC with high brix value and cane yield, basal to middle stem ratio to be maximum i.e. 1, and high lodging resistance index. Thus, harvestability will be beneficial. Harvest time (hrs/acre) exhibits the most pronounced negative impact (-5.876), indicating that an increase in harvesting duration significantly diminishes the response variable. The basal: middle stem diameter ratio and ratooning ability exhibit significant positive effects, indicating that these traits enhance the response. The length of the cane exerts a negative influence, albeit to a lesser extent than the timing of the harvest. The traits of Cane Yield, Cane diameter, lodging resistance and leaf angle inclination were also contributing positively. This confirms that the model primarily incorporates pertinent predictors. The red dashed line at $p = 0.05$ in the plot effectively highlights significant traits. Weight of Single Cane ($p = 0.0566$) although the coefficient is moderately positive, this feature lacks statistical significance and may not serve as a dependable selection criterion. Ratooning ability, and lodging resistance were favorable factors and should be used in breeding projects to improve mechanical harvesting efficiency. Agronomical essential traits like tiller population and cane length positively affect the characteristic, suggesting a trade-off between vegetative vigour and harvest appropriateness. Due to its questionable relevance and high standard error, single cane weight may need more study. The clones viz., 2016A642, 2016A381, 2016A385, 2016A379 were identified as erect, non-lodging, self-stripping, with less crown weight and leaf angle inclination suitable for mechanical harvesting (Table 5).

CONCLUSION

These results guided breeding strategies, mechanization planning, and field management practices. Low GCV and PCV values were put forth by crown weight/

Single cane weight, harvest time and harvest efficiency. Moderate values were depicted by cane yield cane length, cane diameter, and ratio of basal to middle stem diameter and germination per cent. High GCV and PCV values were depicted by tiller population 120@ DAP, NMC, HR Brix %, lodging resistance index, average ratooning ability, 2 and leaf angle inclination. All characters were highly heritable. Selection breeding for variety enhancement based on these qualities may be reliable. However, heritability does not indicate how much genetic improvement genotype selection would produce. The genetic advance as a percentage of mean was high for cane diameter, HR brix%, Single cane weight and Lodging resistance index and leaf angle inclination. Thus additive genetic factors govern these traits, confirming that selection based on phenotypic performance is preferable for variety improvement. Selection for shorter, thicker, lodging-resistant canes improved ratooning ability. Higher basal stem sturdiness, crown weight to single cane weight ratio and leaf angle inclination can greatly improve the overall efficiency of harvesting, especially mechanized harvesting. harvest time, cane structure, and yield-related traits are highlighted as key determinants of the response traits. A high R^2 value indicates that the chosen features together explain a significant proportion of the variations in the end variable (e.g., harvesting efficiency crown weight to single cane weight ratio and leaf angle inclination). This signifies that the model is dependable for predictive and selection judgments in sugarcane breeding of mechanized planning which indicated interplay between yield traits, structural characteristics and operational factors including harvest timing is underscored by the regression analysis. These results can be used to inform the selection of sugarcane genotypes that are appropriate for mechanized harvesting thereby increasing productivity and decreasing labour costs. The

Table 3: Variance analysis results for yield, quality, and mechanized amicable characteristics in sugarcane

SOV	df	Tiller population 120@DAP (000s/h)	NMC (000s/ha)	HR Brix %	Cane yield (t/ha)	Cane length (m)	Cane diameter (cm)	Ratio of basal to middle stem diameter	Lodging resistance index	Single cane weight (kg)	Average Ratoonings ability(t/ha)	Crown weight/Single cane weight	Harvest Time. Hours/acre	Harvest efficiency (%). (Average 9 hours/acre)
Replication	2	49.21	16.10	0.011	19.25	2.14*	0.00311	0.004	1.56	32.1*	36.4	0.003	13.46	21.8*
Treatment	21	606.14*	505.82*	0.71*	2204.41**	441.2*	0.24**	0.31*	453.2*	201.45*	405.21**	11.8*	84.9*	102.4*
Error	42	21.8	14.2	0.02	22.12	11.2	0.0015	0.0024	11.84	14.7	10.52	4.71	9.47	12.8

Table 4: Sugarcane clone genetic parameters for thirteen desirable traits for yield, quality, and Mechanization

Traits	GCV	PCV	Heritability	Genetic advance	G.A percent Mean
Tiller population 120@DAP (000s/h)	26.81	29.51	0.89	23.85	46.32
NMC (000s/h)	21.04	23.24	0.92	18.5	41.51
HR Brix %	20.42	24.51	0.85	34.52	39.63
Cane yield (t/ha)	13.80	16.72	0.91	16.81	46.11
Cane length (m)	14.52	15.33	0.79	15.96	30.32
Cane diameter(cm)	12.56	12.01	0.85	34.82	33.61
Ratio of basal to middle stem diameter	14.84	16.22	0.93	21.34	31.96
Lodging resistance index	20.87	23.24	0.91	32.21	40.05
Single cane weight (kg)	18.11	20.13	0.90	33.84	38.94
Average Ratoonings ability(t/ha)	24.58	27.84	0.85	16.57	33.21
Crown weight/Single cane weight	7.93	9.22	0.87	18.92	36.71
Harvest Time. Hours/acre	8.22	10.82	0.88	20.33	33.94
Harvest efficiency (%)	9.43	11.42	0.84	24.51	34.51

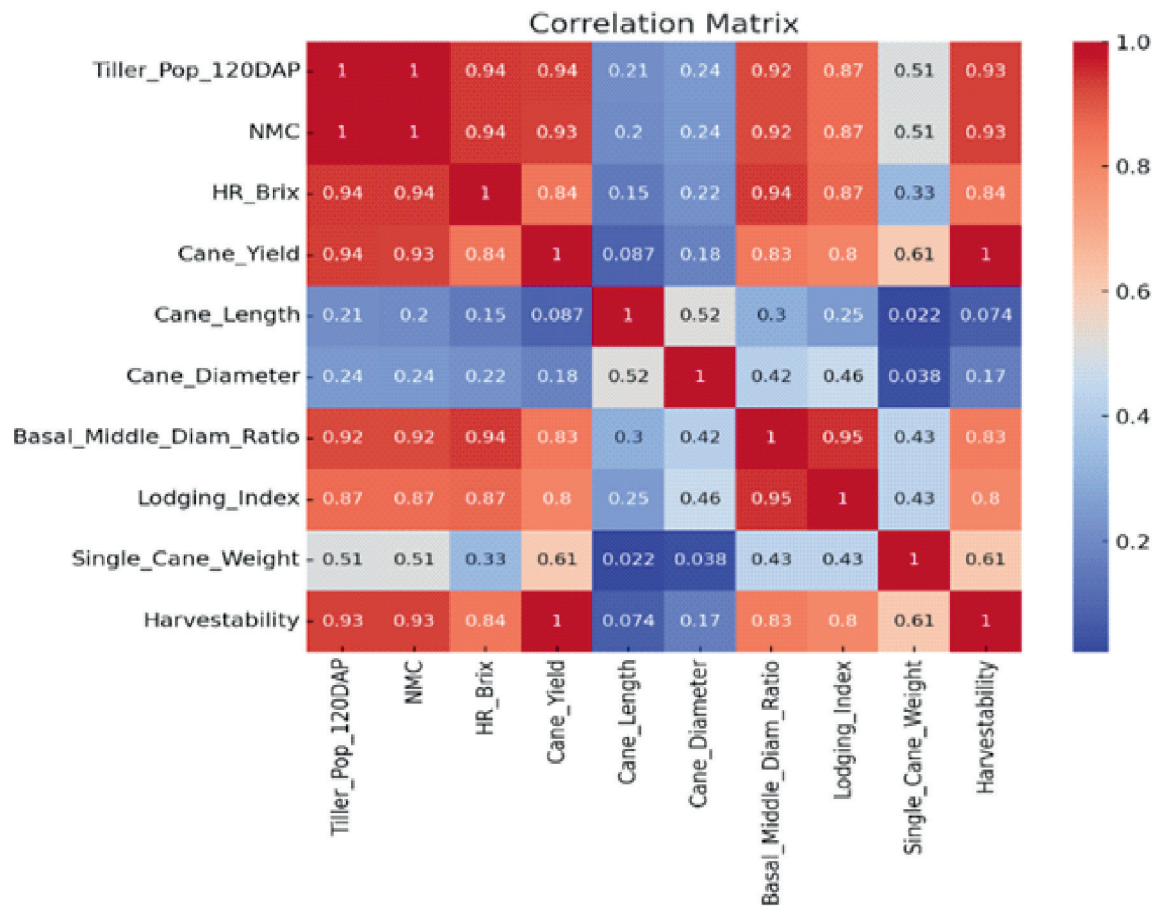


Fig. 1: Heat map of correlation matrix and Graphical representation of Actual and predicted harvestability with mechanical harvesting amicable traits

Table 5: Performance of Erect, Non lodging, Self Stripping, Less Crown weight and leaf angle inclination of new sugarcane varieties suitable for Mechanical Harvesting (Pooled data over Four Years from 2018-2021)

S.No.	Clone	NMC ('000/ha)	Cane yield (t/ha)	Sucrose (%)	CCS (%)	CCS yield (t/ha)	Fibre (%)
1	2016A 642	91.97	101.91	18.34	13.21	13.48	13.38
2	2016A 381	92.51	101.16	19.20	13.43	13.59	14.89
3	2016A 385	91.71	98.62	16.20	10.82	10.85	14.93
4	2016A 379	93.59	96.81	18.42	13.30	12.90	13.88
5	83V 15 (C)	81.59	96.07	19.39	14.31	13.75	14.50
6	87A 298 (C)	84.10	93.15	18.81	13.41	12.53	14.12
7	2016A 719	90.52	92.58	17.23	11.80	11.15	14.52
8	2016A 759	90.47	91.68	18.76	13.08	11.90	15.00
9	2016A 680	86.70	90.75	18.83	13.95	12.67	14.95
10	2016A 685	80.29	89.17	18.51	14.22	12.69	13.31
11	2016A 674	94.55	87.82	18.81	14.33	12.62	13.36
12	2016A 644	78.61	7281	17.50	13.82	10.03	13.29
	CD (0.05%)	17.87	18.71	0.66	0.83	2.44	
	C.V (%)	7.48	9.86	3.16	2.65	9.67	

clones viz., 2016A642,2016A381,2016A385,2016A379 were identified as erect, non lodging, self stripping, with less crown weight and leaf angle inclination suitable mechanical harvesting.

ACKNOWLEDGEMENTS

The authors are highly thankful to Acharya NG Ranga Agricultural University, RARS, Anakapalle for creating facilities for carrying out of Research work at RARS, Anakapalle.

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